

NEW

HOW IT WORKS

# INCREDIBLE EARTH

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD WE LIVE IN

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FACTS ABOUT  
OUR PLANET



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TENTH  
EDITION



Experience  
wild weather



Discover  
the animal  
kingdom



Witness extreme  
natural phenomena





# Welcome to

## HOW IT WORKS

# INCREDIBLE EARTH

The planet we live on is a remarkable place, with incredible things happening everywhere, all the time. But have you ever wondered how or why these things occur? How the Earth was created? How we predict the weather? How fossils form? What causes earthquakes? Which animals glow in the dark? Incredible Earth provides answers to all these questions and more as it takes you on a thrilling journey through everything you need to know about the world we live in. Covering the scientific explanations behind weather phenomena, poisonous plants, extreme landscapes and volatile volcanoes, as well as the amazing creatures found throughout the animal kingdom and in our homes, there is something for everyone to enjoy. Packed full of fascinating facts, gorgeous photography and insightful diagrams, Incredible Earth will show you just how awe-inspiring our planet really is.

J L  
F U T U R E  
T R

# HOW IT WORKS

# INCREDIBLE EARTH

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**Distributed by** Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU  
www.marketforce.co.uk Tel: 0203 787 9001

## Incredible Earth Tenth Edition

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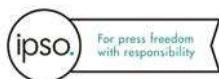
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Part of the  
**HOW IT WORKS**  
bookazine series



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ANIMALS

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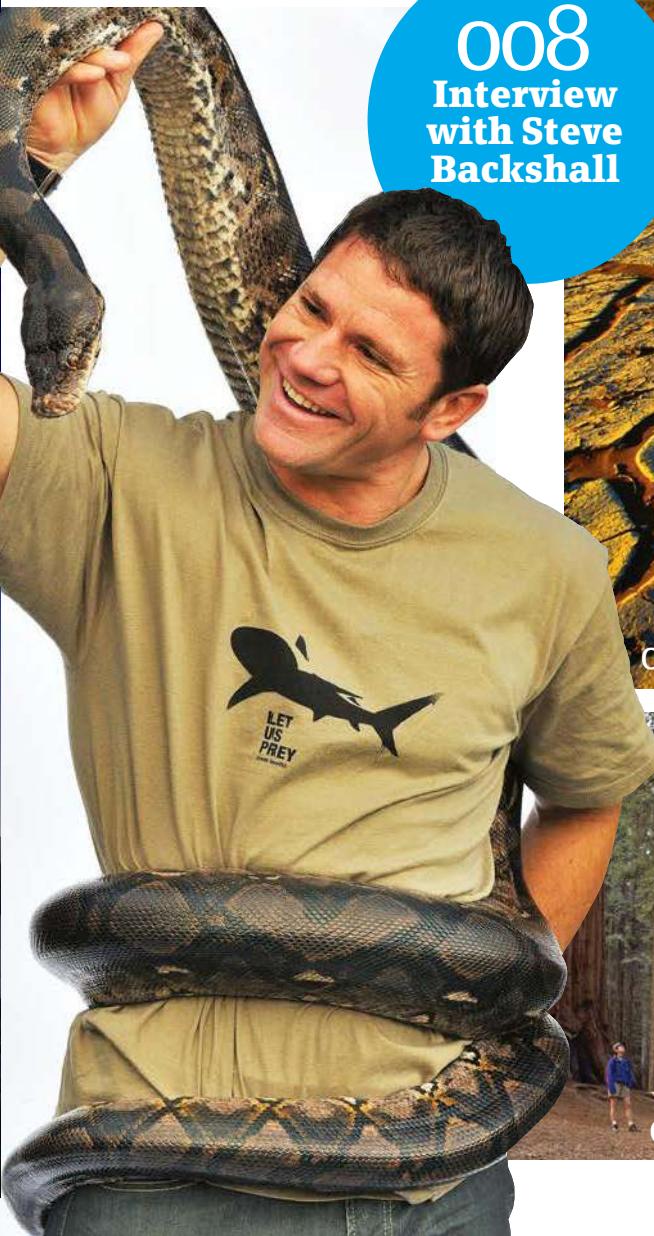


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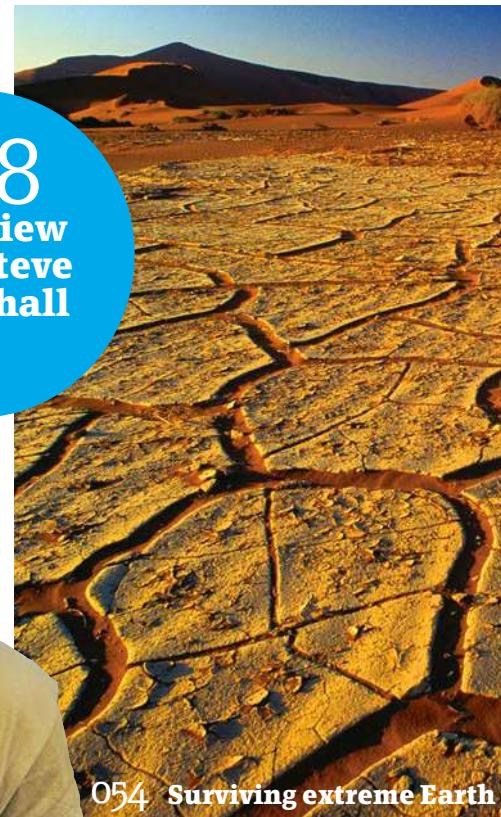


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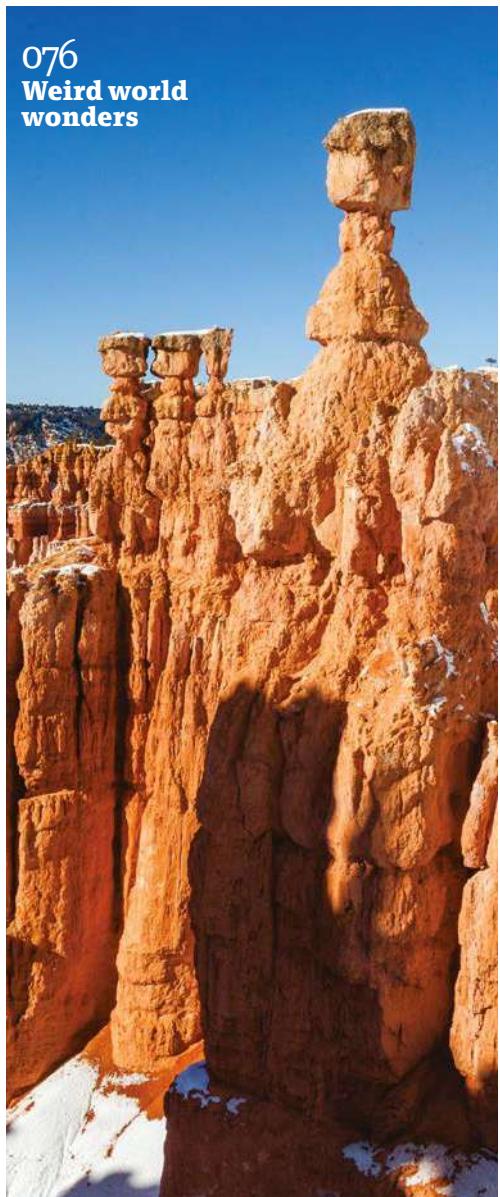
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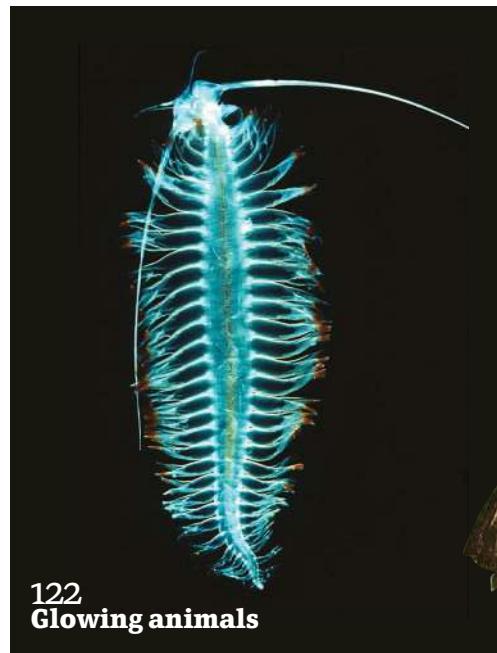
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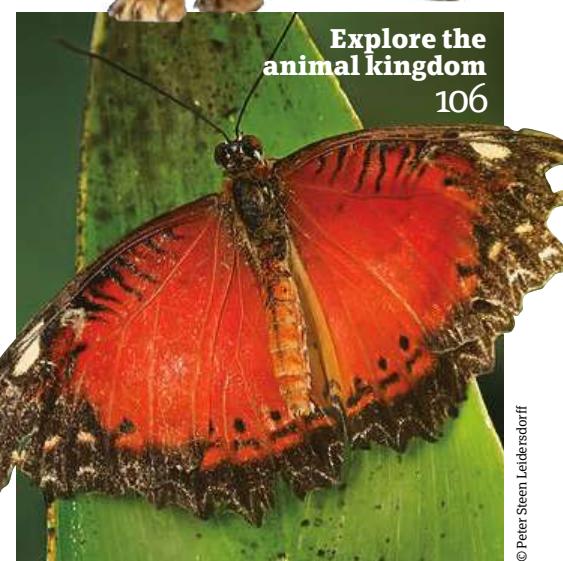
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# Wild encounters

Daring adventurer and wildlife enthusiast Steve Backshall discusses life on the edge

**A**fter a few years of living in the jungle, Steve Backshall earned the title 'Adventurer in Residence' for National Geographic Channel in 1998. He moved to the BBC in 2003, and has been making programmes about exploration and wildlife ever since. Backshall has come face-to-face with some of the planet's most fearsome predators. He confesses: "I am much more frightened in a big city on a Saturday night after pub closing time than I would be tracking lions on foot." Backshall is going on a UK tour to share stories and reveal some of the behind-the-scenes action from his expeditions. We spoke to him about survival tips, death-defying climbs and dancing with whales.

## Your TV shows are edge-of-your-seat viewing, but what don't we see on screen?

The outtakes usually involve animals doing the opposite of what I want. There are countless examples of animals ignoring me, breaking wind in my face, snapping and snarling, and doing other things that you don't expect them to.

## What is the most difficult part of your job?

I think the most difficult part is how long it can take to find particular animals. Some things I can go out and find without too much trouble. Other things take inordinate amounts of effort and patience, and it can start to get quite stressful knowing somehow you've got to film this show and you haven't found the animal yet.

## Have there been any moments in your career where you've genuinely feared for your life?

The expedition involving the first ascent of Amaurai Tepui, a vertical, sandstone-sided mountain in Venezuela. It was the follow-on to the highly successful first ascent we'd done a few years before. We were really excited about it, and it ended up being much more dangerous than we thought. We had rock-fall tumbling around our ears, a massive storm that raged in. It was unsafe. Even the guys on the team, who are some of the best climbers in the world, were terrified.

## What's the greatest discovery you've made?

I've been lucky enough to take the first light into cave systems that have never been explored, to make first ascents of mountains, first descents of white-water rivers, and to hold animals in my hand that are new to science. Perhaps the greatest

of those was on the *Lost Land of the Volcano* expedition. We went to New Guinea with a team of scientists, and discovered as many as 20 new animals, including the world's largest species of giant rat, a new marsupial, a new bat and about ten new species of frog.

## Do you have a bucket list of animals you want to see?

There are a lot of animals that I've put a huge amount of work into finding and still haven't seen. I've spent at least two months on the road looking for mountain lions and never seen one. I would love to go to the Karakoram in Pakistan to climb and look for snow leopards. That would be a dream. The longer I do this, the more I see what is left to do, and the bigger my list becomes.

## What's the most beautiful thing in nature?

Probably free-diving alongside a female sperm whale, who was interacting with me, almost dancing with me, underwater. She was mirroring my movements, replicating the same somersaults I was doing and looking me in the eye the whole time. It was like dancing a ballet with an animal that must have weighed ten tons.

## Close to extinction

As a dedicated ambassador for animal conservation, Steve Backshall reveals the three species disappearing from our planet faster than any others

### Vultures

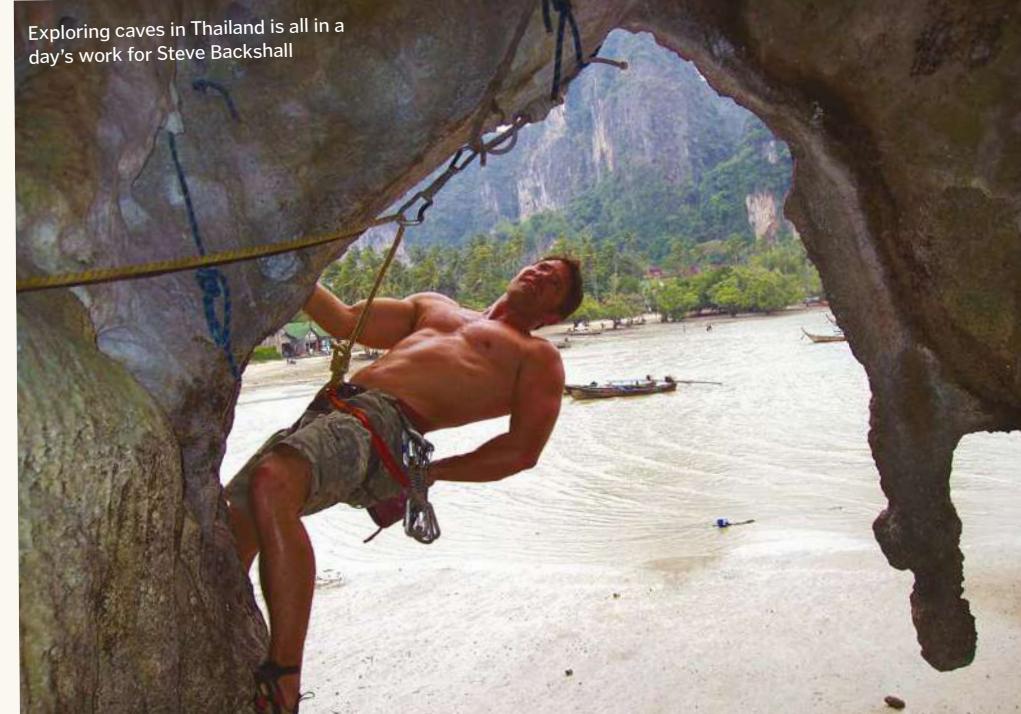
Numbers have plummeted since the 1980s due to the veterinary drug diclofenac. It's passed on to them when they eat the carcasses of animals that have been treated with the drug, and this causes kidney failure.

### Frogs

The chytrid fungus is responsible for causing a global mass extinction of frogs. It infects a frog's skin, causing it to thicken and making it difficult for the animal to absorb the water and salts it needs to survive.

### Sharks

The threat to sharks comes mainly from humans. Longlining, a technique for catching tuna, results in sharks getting hooked by accident. Fishermen will often then remove their fins to sell, due to the high demand for shark fin soup, a delicacy in Asia.





Steve has wrestled with anacondas, vipers and cobras, but his only snakebite was from an adder in the UK



Steve has climbed some of the world's most dangerous mountains

#### **What is the scariest animal on the planet?**

The scariest is the hippo because it is so unpredictable. Snakes, scorpions and spiders almost have a set of rules for how they will behave in each situation. Hippos are much more intelligent than you might think, much faster and have a tendency to be aggressive as well, so that coupled with the fact that you don't know what they're going to do next makes them potentially the most dangerous animal to be around.

#### **Where is your favourite place on Earth?**

Probably the Himalayas. I get a chance to go back there quite often. It's a place where the grandeur and majesty of the landscape is phenomenal. It changes constantly throughout the day, week and year. It's a place with many unclimbed peaks and great challenges, so I love it.

#### **What item of kit could you never miss?**

Superglue. It was apparently developed in the Vietnam War for surgical use, and I still use it for that now. I apply it to blisters and minor cuts and it can also be used to hold together elements of your kit. It's one of the first things that I pack.

#### **What useful survival tip have you received?**

When you're working with predatory animals, never run. Predators, generally speaking, have learnt over generations to fear us human beings. If you encounter even potentially very dangerous animals, such as big cats, in the wild, the chances of them attacking you are close to zero, unless you run. The second you run, you are doing what prey does and their instincts kick in and they will chase you down and attack you. Stand still and you'll probably get away with it.

#### **Any advice for aspiring adventurers?**

Start small and close to home. Adventure begins in your own back yard. Learn about things you can find right here in the UK: the bugs and invertebrates that live in your garden. Particularly at this time of year, when it's warm, there will be plenty of things in your garden that you might not know about but have incredible, interesting lives.





# INCREDIBLE STORY OF EARTH

Ancient and teeming with life, Earth is a truly amazing planet, with a fascinating tale to tell...

**T**oday, science has revealed much about our planet, from how it formed and has evolved over billions of years through to its current position in the universe. Indeed, right now we have a clearer picture of Earth than ever before.

And what a terrifying and improbable picture it is. A massive spherical body of metal, rock, liquid and gas suspended perilously within a vast void by an invisible, binding force. It is a body that rotates continuously, is tilted on an axis by 23 degrees and orbits once every 365.256 solar days around a flaming ball of hydrogen 150 million kilometres (93 million miles) away. It is a celestial object that, on face value, is mind-bendingly unlikely.

As a result, the truth about our planet and its history eluded humans for thousands of years. Naturally, as beings that like to know the answers to *how* and *why*, we have come up with many ways to fill in the gaps. The Earth

was flat; the Earth was the centre of the universe; and, of course, all manner of complex and fiercely defended beliefs about creation.

But then in retrospect, who could have ever guessed that our planet formed from specks of dust and mineral grains in a cooling gas cloud of a solar nebula? That the spherical Earth consists of a series of fluid elemental layers and plates around an iron-rich molten core? Or that our world is over 4.5 billion years old and counting? Only some of the brightest minds over many millennia could grant an insight into these geological realities.

While Earth may only be the fifth biggest planet in our Solar System, it is by far the most awe-inspiring. Perhaps most impressive of all, it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang. Here, we celebrate our world in all its glory, charting its journey from the origins right up to the present and what lies ahead.

***“Earth is awe-inspiring... it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang”***



# From dust to planet

To get to grips with how the Earth formed, first we need to understand how the Solar System as a whole developed – and from what. Current evidence suggests that the beginnings of the Solar System lay some 4.6 billion years ago with the gravitational collapse of a fragment of a giant molecular cloud.

In its entirety this molecular cloud – an interstellar mass with the size and density to form molecules like hydrogen – is estimated to have been 20 parsecs across, with the fragment just five per cent of that. The gravitationally induced collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today and consisting primarily of hydrogen, helium and lithium gases generated by Big Bang nucleosynthesis (BBN).

At the heart of this pre-solar nebula, intense gravity – along with supernova-induced over-density within the core, high gas pressures, nebula rotation (caused by angular momentum) and fluxing magnetic fields – in conjunction caused it to contract and flatten into a protoplanetary disc. A hot, dense protostar formed at its centre, surrounded by a 200-astronomical-unit cloud of gas and dust.

It is from this solar nebula's protoplanetary disc that Earth and the other planets emerged. While the protostar would develop a core temperature and pressure to instigate hydrogen fusion over a period of approximately 50 million years, the cooling gas of the disc would produce mineral grains through condensation, which would amass into tiny meteoroids. The latest evidence indicates that the oldest of the meteoroidal material formed about 4.56 billion years ago.

As the dust and grains were drawn together to form ever-larger bodies of rock (first chondrules, then chondritic meteoroids), through continued accretion and collision-induced compaction, planetesimals and then protoplanets appeared – the latter being the precursor to all planets in the Solar System. In terms of the formation of Earth, the joining of multiple planetesimals meant it developed a gravitational attraction powerful enough to sweep up additional particles, rock fragments and meteoroids as it rotated around the Sun. The composition of these materials would, as we shall see over the page, enable the protoplanet to develop a superhot core.



*"The collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today"*

## The history of Earth

Follow the major milestones in our planet's epic development  
\*(BYA = billion years ago)

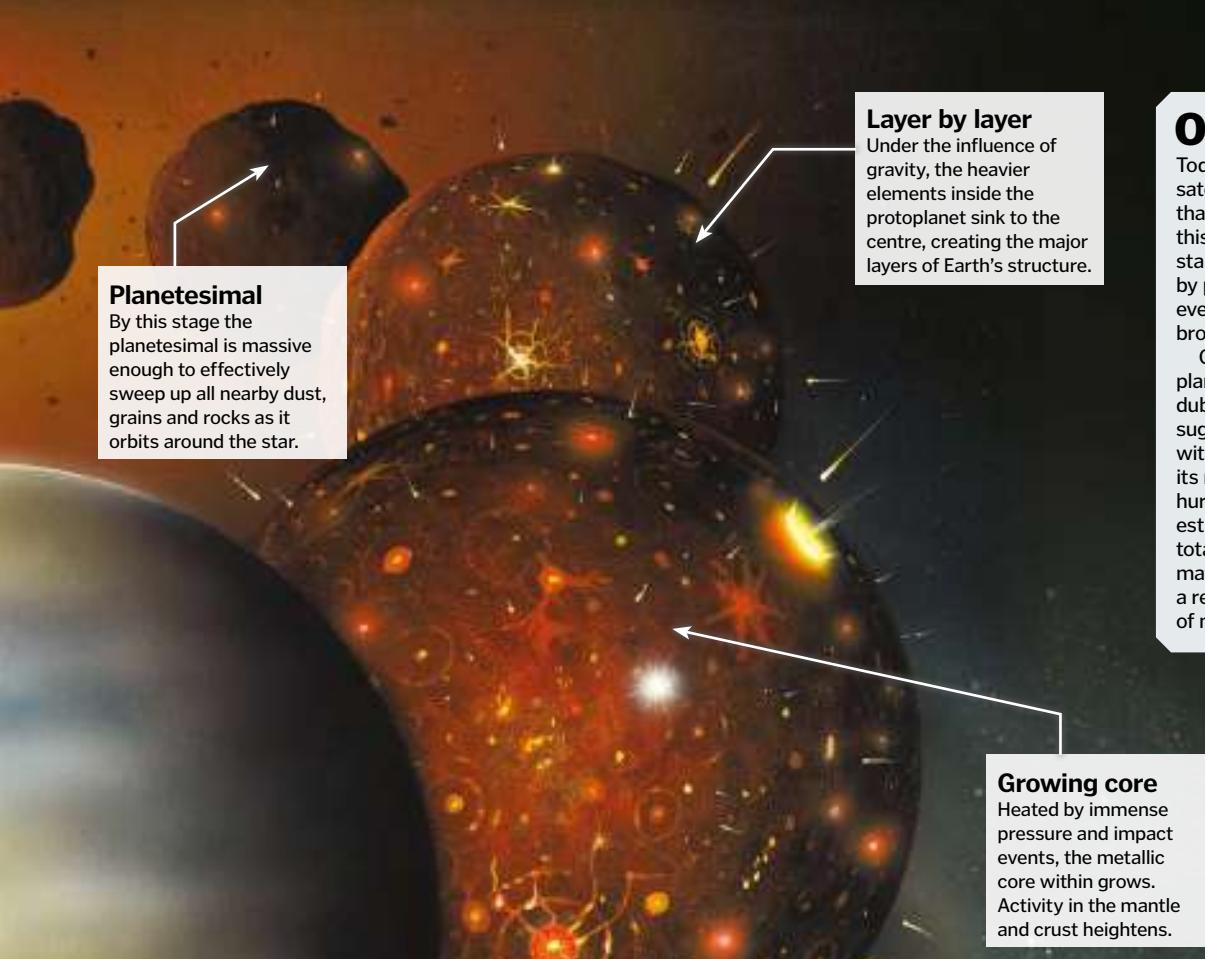
**13.8 BYA\***

**Big Bang fallout**  
Nucleosynthesis as a result of the Big Bang leads to the gradual formation of chemical elements on a huge scale.

**4.6 BYA**

**New nebula**  
A fragment of a giant molecular cloud experiences a gravitational collapse and becomes a pre-solar nebula.





## Origins of the Moon

Today most scientists believe Earth's sole satellite formed off the back of a collision event that occurred roughly 4.53 billion years ago. At this time, Earth was in its early development stage and had been impacted numerous times by planetesimals and other rocky bodies – events that had shock-heated the planet and brought about the expansion of its core.

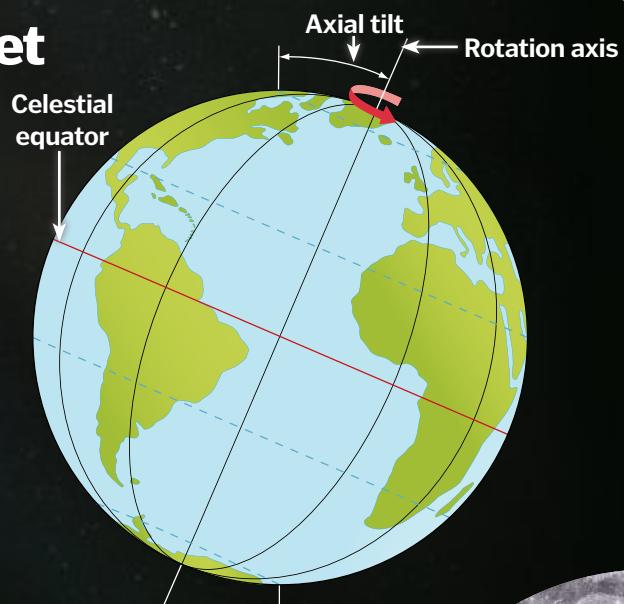
One collision, however, seems to have been a planet-sized body around the size of Mars – dubbed Theia. Basic models of impact data suggest Theia struck Earth at an oblique angle, with its iron core sinking into the planet, while its mantle, as well as that of Earth, was largely hurled into orbit. This ejected material – which is estimated to be roughly 20 per cent of Theia's total mass – went on to form a ring of silicate material around Earth and then coalesce within a relatively short period (ranging from a couple of months up to 100 years) into the Moon.

## Why does our planet have an axial tilt?

Earth's axial tilt (obliquity), which is at 23.4 degrees in respect to the planet's orbit currently, came about approximately 4.5 billion years ago through a series of large-scale impacts from planetesimals and other large bodies (like Theia). These collisions occurred during the early stages of the planet's development and generated forces great enough to disrupt Earth's alignment, while also producing a vast quantity of debris.

While our world's obliquity might be 23.4 degrees today, this is by no means a fixed figure, with it varying over long periods due to the effects of precession and orbital resonance.

For example, for the past 5 million years, the axial tilt has varied from 22.2-24.3 degrees, with a mean period lasting just over 41,000 years. Interestingly, the obliquity would be far more variable if it were not for the presence of the Moon, which has a stabilising effect.



### Atmosphere

Thanks to volcanic outgassing and ice deposition via impacts, Earth develops an intermediary carbon-dioxide rich atmosphere.

### 4.57 BYA

#### Protostar

Several million years later, the precursor to the Sun (a T Tauri-type star) emerges at the heart of the nebula.



### 4.56 BYA

#### Disc develops

Around the T Tauri star a protoplanetary disc of dense gas begins to form and then gradually cools.

### 4.54 BYA

#### Planet

As dust and rock gather, Earth becomes a planet, with planetary differentiation leading to the core's formation.

### 4.53 BYA

#### Birth of the Moon

Theia, a Mars-sized body, impacts with the Earth. The resulting debris rises into orbit and will coalesce into the Moon.





## Earth's structure

As the mass of the Earth continued to grow, so did its internal pressure. This in partnership with the force of gravity and 'shock heating' – see boxout opposite for an explanation – caused the heavier metallic minerals and elements within the planet to sink to its centre and melt. Over many years, this resulted in the development of an iron-rich core and, consequently, kick-started the interior convection which would transform our world.

Once the centre of Earth was hot enough to convect, planetary differentiation began. This is the process of separating out different elements of a planetary body through both physical and chemical actions. Simply put, the denser materials of the body sink towards the core and the less dense rise towards the surface. In Earth's case, this would eventually lead to the distinct layers of inner core, outer core, mantle and crust – the latter developed largely through outgassing.

Outgassing in Earth occurred when volatile substances located in the lower mantle began to melt approximately 4.3 billion years ago. This partial melting of the interior caused chemical separation, with resulting gases rising up through the mantle to the surface, condensing and then crystallising to form the first crustal layer. This original crust proceeded to go through a period of recycling back into the mantle through convection currents, with successive outgassing gradually forming thicker and more distinct crustal layers.

The precise date when Earth gained its first complete outer crust is unknown, as due to the recycling process only incredibly small parts of it remain today. Certain evidence, however, indicates that a proper crust was formed relatively early in the Hadean eon (4.6–4 billion years ago). The Hadean eon on Earth was

characterised by a highly unstable, volcanic surface (hence the name 'Hadean', derived from the Greek god of the underworld, Hades). Convection currents from the planet's mantle would elevate molten rock to the surface, which would either revert to magma or harden into more crust.

Scientific evidence suggests that outgassing was also the primary contributor to Earth's first atmosphere, with a large region of hydrogen and helium escaping – along with ammonia, methane and nitrogen – considered the main factor behind its initial formation.

By the close of the Hadean eon, planetary differentiation had produced an Earth that, while still young and inhospitable, possessed all the ingredients needed to become a planet capable of supporting life.

But for anything organic to develop, it first needed water...

### Outer core

Unlike the inner core, Earth's outer core is not solid but liquid, due to less pressure. It is composed of iron and nickel and ranges in temperature from 4,400°C (7,952°F) at its outer ranges to 6,100°C (11,012°F) at its inner boundary. As a liquid, its viscosity is estimated to be ten times that of liquid metals on the surface. The outer core was formed by only partial melting of accreted metallic elements.

### Inner core

The heaviest minerals and elements are located at the centre of the planet in a solid, iron-rich heart. The inner core has a radius of 1,220km (760mi) and has the same surface temperature as the Sun (around 5,430°C/9,800°F). The solid core was created due to the effects of gravity and high pressure during planetary accretion.

**"Outgassing occurred when volatile substances in the lower mantle began to melt 4.3 billion years ago"**

### 4.4 BYA

#### Surface hardens

Earth begins developing its progenitor crust. This is constantly recycled and built up through the Hadean eon.

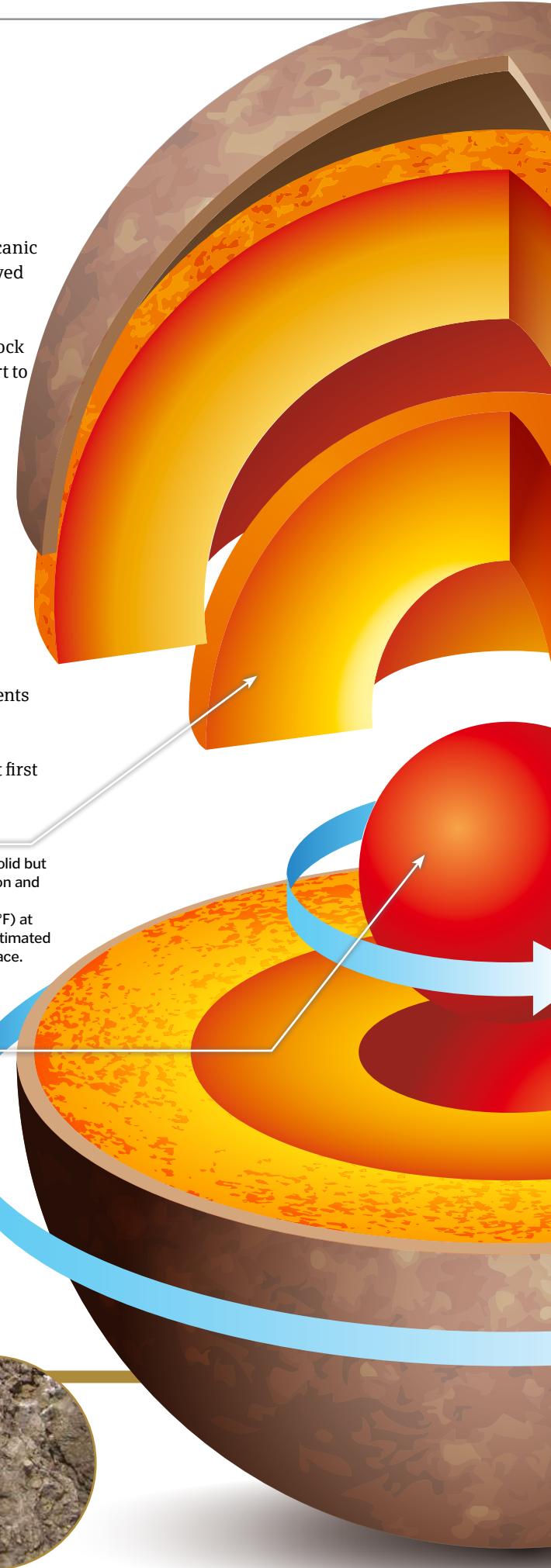
### Early atmosphere

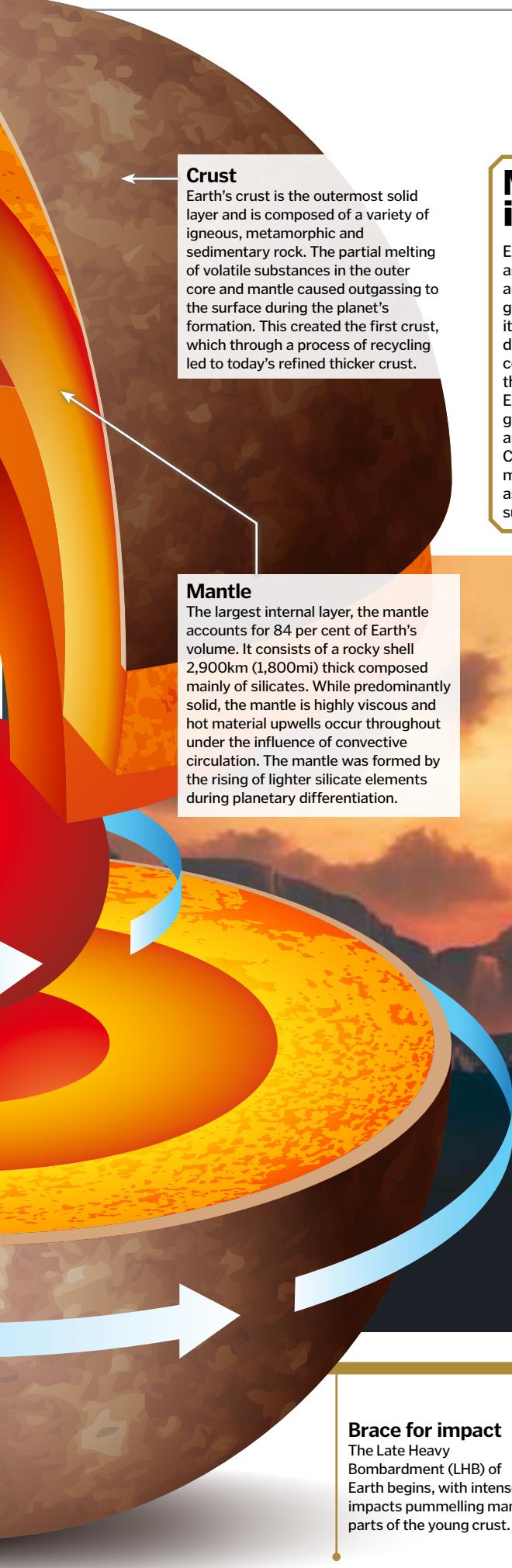
Outgassing and escaping gases from surface volcanism form the first atmosphere around the planet. It is nitrogen heavy.

### 4.28 BYA

#### Ancient rocks

A number of rocks have been found in northern Québec, Canada, that date from this period. They are volcanic deposits.





### Crust

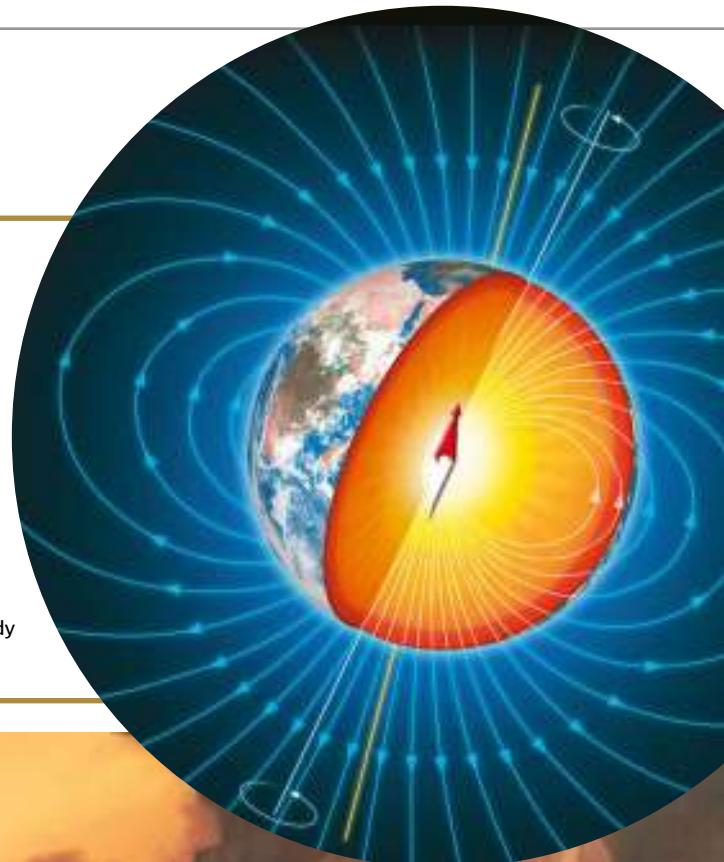
Earth's crust is the outermost solid layer and is composed of a variety of igneous, metamorphic and sedimentary rock. The partial melting of volatile substances in the outer core and mantle caused outgassing to the surface during the planet's formation. This created the first crust, which through a process of recycling led to today's refined thicker crust.

### Mantle

The largest internal layer, the mantle accounts for 84 per cent of Earth's volume. It consists of a rocky shell 2,900km (1,800mi) thick composed mainly of silicates. While predominantly solid, the mantle is highly viscous and hot material upwells occur throughout under the influence of convective circulation. The mantle was formed by the rising of lighter silicate elements during planetary differentiation.

## Magnetic field in the making

Earth's geomagnetic field began to form as soon as the young planet developed an outer core. The outer core of Earth generates helical fluid motions within its electrically conducting molten iron due to current loops driven by convection. As a result, the moment that convection became possible in Earth's core it began to develop a geomagnetic field – which in turn was amplified by the planet's rapid spin rate. Combined, these enabled Earth's magnetic field to permeate its entire body as well as a small region of space surrounding it – the magnetosphere.



## Shock heating explained

During the accretion to its present size, Earth was subjected to a high level of stellar impacts by space rocks and other planetesimals too. Each of these collisions generated the effect of shock heating, a process in which the impactor and resultant shock wave transferred a great deal of energy into the forming planet. For meteorite-sized bodies, the vast majority of this energy was transferred across the planet's

surface or radiated back off into space, however in the case of much larger planetesimals, their size and mass allowed for deeper penetration into the Earth. In these events the energy was distributed directly into the planet's inner body, heating it well beneath the surface. This heat influx contributed to heavy metallic fragments deep underground melting and sinking towards the core.

### Brace for impact

The Late Heavy Bombardment (LHB) of Earth begins, with intense impacts pummelling many parts of the young crust.

### 4 BYA

#### Archean

The Hadean eon finally comes to an end and the new Archean period begins.

### 3.9 BYA

#### Ocean origins

Earth is now covered with liquid oceans due to the release of trapped water from the mantle and from asteroid/comet deposition.



### 3.6 BYA

#### Supercontinent

Our world's very first supercontinent, Vaalbara, begins to emerge from a series of combining cratons.



## Supercontinent development

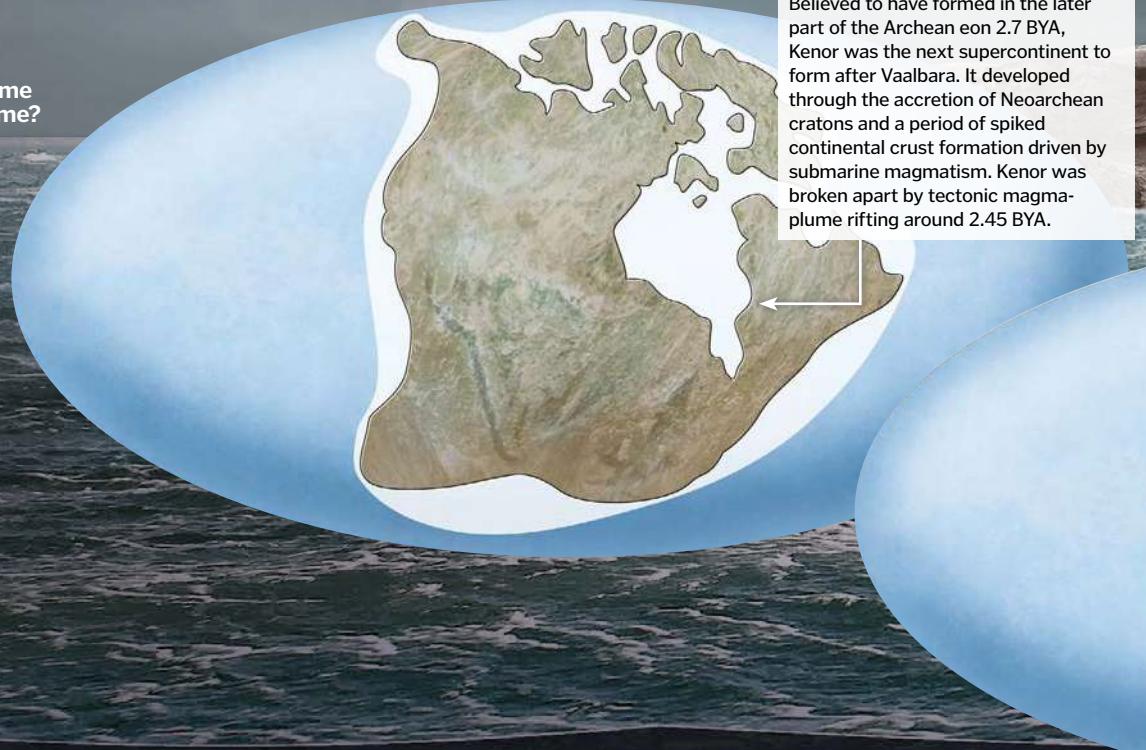
Where did the earliest landmasses come from and how did they change over time?

### It started with Vaalbara...

Approximately 3.6 billion years ago, Earth's first supercontinent – Vaalbara – formed through the joining of several large continental plates. Data derived from parts of surviving cratons from these plates – eg the South African Kaapvaal and Australian Pilbara; hence 'Vaal-bar-a' – show similar rock records through the Archean eon, indicating that, while now separated by many miles of ocean, they once were one. Plate tectonics, which were much fiercer at this time, drove these plates together and also were responsible for separating them 2.8 billion years ago.

### Kenor

Believed to have formed in the later part of the Archean eon 2.7 BYA, Kenor was the next supercontinent to form after Vaalbara. It developed through the accretion of Neoarchean cratons and a period of spiked continental crust formation driven by submarine magmatism. Kenor was broken apart by tectonic magma-plume rifting around 2.45 BYA.



## Formation of land and sea

Current scientific evidence suggests that the formation of liquid on Earth was, not surprisingly, a complex process. Indeed, when you consider the epic volcanic conditions of the young Earth through the Hadean eon, it's difficult to imagine exactly how the planet developed to the extent where today 70 per cent of its surface is covered with water. The answer lies in a variety of contributory processes, though three can be highlighted as pivotal.

The first of these was a drop in temperature throughout the late-Hadean and Archean eons. This cooling caused outgassed volatile substances to form an atmosphere around the planet – see the opposite boxout for more details – with sufficient pressure for retaining liquids. This outgassing also transferred a large quantity of water that was trapped in the planet's internal accreted material to the

surface. Unlike previously, now pressurised and trapped by the developing atmosphere, it began to condense and settle on the surface rather than evaporate into space.

The second key liquid-generating process was the large-scale introduction of comets and water-rich meteorites to the Earth during its formation and the Late Heavy Bombardment period. These frequent impact events would cause the superheating and vaporisation of many trapped minerals, elements and ices, which then would have been adopted by the atmosphere, cooled over time, condensed and re-deposited as liquid on the surface.

The third major contributor was photodissociation – which is the separation of substances through the energy of light. This process caused water vapour in the developing upper atmosphere to separate into molecular hydrogen and molecular oxygen, with the former escaping the planet's influence. In turn, this led to an increase in the partial pressure of oxygen on the planet's surface, which through its interactions with surface materials gradually elevated vapour pressure to a level where yet more water could form.

The combined result of these processes – as well as others – was a slow buildup of liquid

***"This erosion of Earth's crustal layer aided the distinction of cratons – the base for some of the first continental landmasses"***

### 3.5 BYA

#### Early bacteria

Evidence suggests that the earliest primitive life forms – bacteria and blue-green algae – begin to emerge in Earth's growing oceans at this time.

### 3.3 BYA

#### Hadean discovery

Sedimentary rocks have been found in Australia that date from this time. They contain zircon grains with isotopic ages between 4.4 and 4.2 BYA.



### 2.9 BYA

#### Island boom

The formation of island arcs and oceanic plateaux undergoes a dramatic increase that will last for about another 200 million years.







# The development of life

Of all the aspects of Earth's development, the origins of life are perhaps the most complex and controversial. That said, there's one thing upon which the scientific community as a whole agrees: that according to today's evidence, the first life on Earth would have been almost inconceivably small-scale.

There are two main schools of thought for the trigger of life: an RNA-first approach and a metabolism-first approach. The RNA-first hypothesis states that life began with self-replicating ribonucleic acid (RNA) molecules, while the metabolism-first approach believes it all began with an ordered sequence of chemical reactions, ie a chemical network.

Ribozymes are RNA molecules that are capable of both triggering their own replication and also the construction of proteins – the main building blocks and working molecules in cells. As such, ribozymes seem good candidates for the starting point of all life. RNA is made up of nucleotides, which are biological molecules composed of a nucleobase (a nitrogen compound), five-carbon sugar and phosphate groups (salts). The presence of these chemicals and their fusion is the base for the RNA-world theory, with RNA capable of acting as a less stable version of DNA.

This theory begs two questions: one, were these chemicals present in early Earth and, two, how were they first fused? Until recently, while some success has been achieved in-vitro showing that activated ribonucleotides can polymerise (join) to form RNA, the key issue in replicating this formation was showing how ribonucleotides could form from their constituent parts (ie ribose and nucleobases).

Interestingly in a recent experiment reported in *Nature*, a team showed that pyrimidine ribonucleobases can be formed in a process that bypasses the fusion of ribose and nucleobases, passing instead through a series of other processes that rely on the presence of other compounds, such as cyanoacetylene and glycolaldehyde – which are believed to have

been present during Earth's early formation. In contrast, the metabolism-first theory suggests that the earliest form of life on Earth developed from the creation of a composite-structured organism on iron-sulphide minerals common around hydrothermal vents.

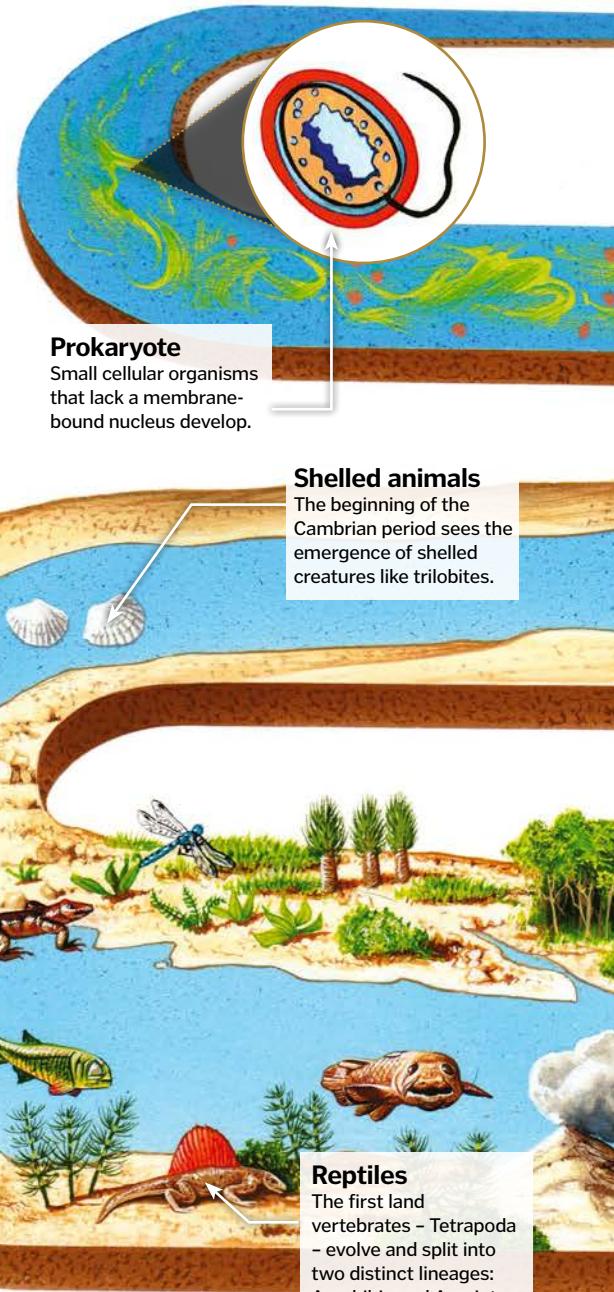
The theory goes that under the high pressure and temperatures experienced at these deep-sea geysers, the chemical coupling of iron salt and hydrogen sulphide

**Fish**  
The world's first fish evolved in the Cambrian explosion, with jawless ostracoderms developing the ability to breathe exclusively through gills.

**Insects**  
During the Devonian period primitive insects begin to emerge from the pre-existing Arthropoda phylum.

produced a composite structure with a mineral base and a metallic centre (such as iron or zinc).

The presence of this metal, it is theorised, triggered the conversion of inorganic carbon into organic compounds and kick-started constructive metabolism (forming new molecules from a series of simpler units). This process became self-sustaining by the generation of a sulphur-dependent metabolic cycle. Over time the cycle expanded and became more efficient, while simultaneously



producing ever-more complex compounds, pathways and reaction triggers.

As such, the metabolism-first approach describes a system in which no cellular components are necessary to form life; instead, it started with a compound such as pyrite – a mineral which was abundant in early Earth's oceans. When considering that the oceans during the Hadean and early-Archean eons were extremely acidic – and that the planet's overall temperature was still very high –

## 1.4 BYA

### Fungi

The earliest signs of fungi according to current fossil evidence suggest they developed here in the Proterozoic.

## 1.2 BYA

**Reproduction**  
With the dawn of sexual reproduction, the rate of evolution increases rapidly and exponentially.

## 542 MYA

### Explosion

The Cambrian explosion occurs – a rapid diversification of organisms that leads to the development of most modern phyla (groups).



## 541 MYA

### Phanerozoic

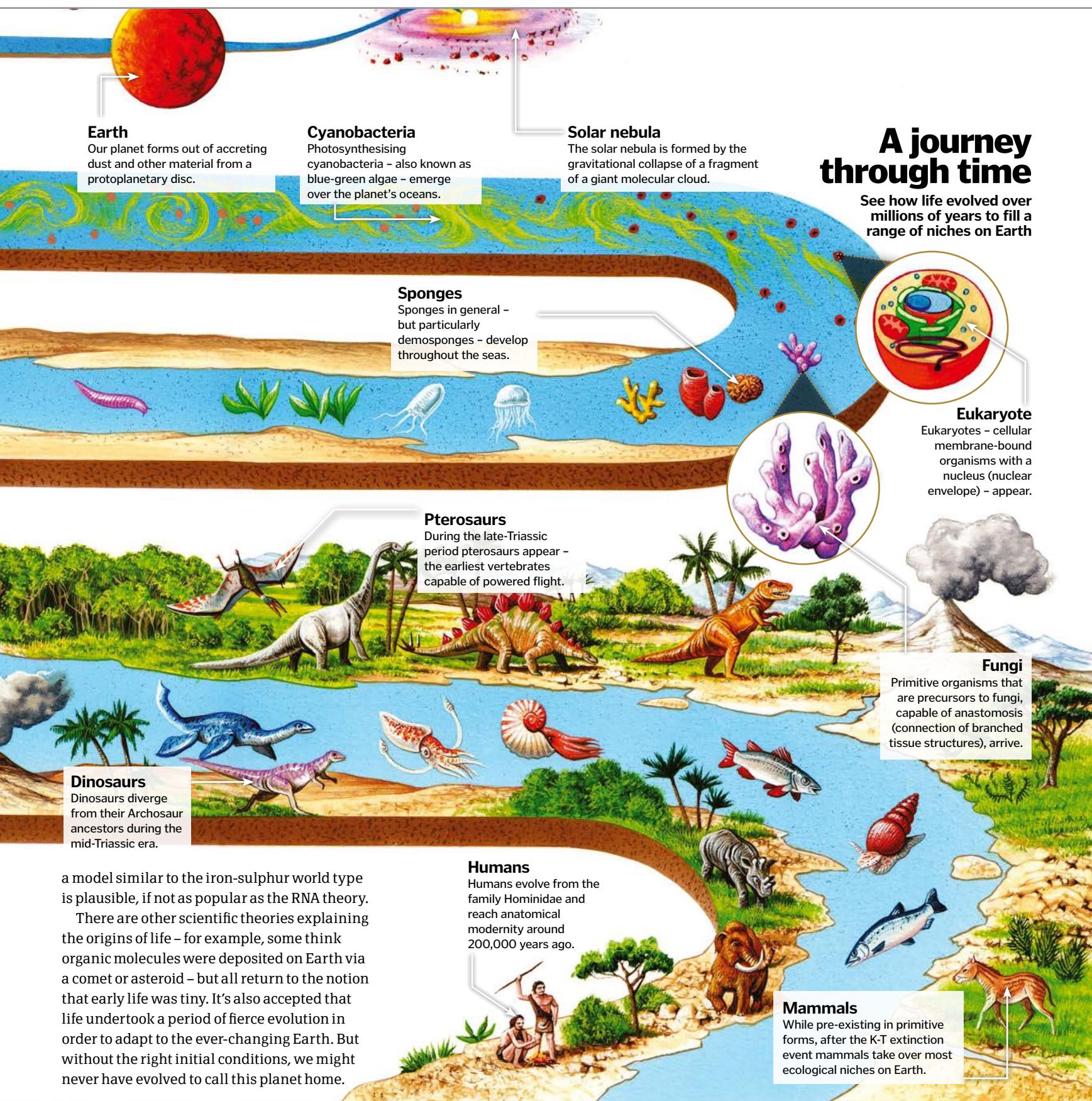
The Proterozoic eon finally draws to a close and the current geologic eon – the Phanerozoic – commences.

## 106 MYA

### Spinosaurus

The largest theropod dinosaur ever to live on Earth, weighing up to an astonishing 20 tons, emerges at this time.





### 65.5 MYA

#### K-T event

The Cretaceous-Palaeogene extinction event occurs, wiping out half of all animal species on Earth, including the dinosaurs.

### 55 MYA

#### Birds take off

Bird groups begin to diversify dramatically, with many species still around today – such as parrots.

### 2 MYA

#### Homo genus

The first members of the genus *Homo*, of which humans are members, appear in the fossil record.

### 350,000 years ago

#### Neanderthal

Neanderthals evolve and spread across Eurasia. They become extinct 220,000 years later.

### 200,000 years ago

#### First human

Anatomically modern humans evolve in Africa; 150,000 years later they start to move farther afield.





# WEATHER WONDERS

## 50 amazing weather facts 022



- 022 50 amazing facts about the weather**  
Your burning climate questions are answered
- 028 How do jet streams work?**  
Invisible phenomena vital to our climate
- 030 Predicting the weather**  
Discover how we get forecasts for the days ahead
- 032 Lightning**  
Learn the science behind how and why lightning strikes



028  
Jet streams





**How do we  
predict the  
weather?**

**030**



**Lightning**  
**032**



How many lightning strikes are there each second globally?  
**100**

# 50 AMAZING FACTS ABOUT WEATHER

How many thunderstorms break out worldwide at any given moment?  
**2,000**

How hot is the Sun?  
The core is around **15,000,000 °C**  
[27,000,000 °F]

We answer your burning questions about the incredible variety and awesome power of the planet's most intriguing climatic phenomena

We like to be able to control everything, but weather – those changes in the Earth's atmosphere that spell out rain, snow, wind, heat, cold and more – is one of those things that is just beyond our power. Maybe that's why a cloudless sunny day or a spectacular display of lightning both have the ability to delight us. Meteorologists have come a long way in their capability to predict weather patterns,

track changes and forecast what we can expect to see when we leave our homes each day. But they're not always right. It's not their fault; we still don't completely understand all of the processes that contribute to changes in the weather.

Here's what we do know: all weather starts with contrasts in air temperature and moisture in the atmosphere. Seems simple, right? Not exactly. Temperature and moisture vary greatly depending

on a huge number of factors, like the Earth's rotation, where you're located, the angle at which the Sun is hitting it at any given time, your elevation, and your proximity to the ocean. These all lead to changes in atmospheric pressure. The atmosphere is chaotic, meaning that a very small, local change can have a far-reaching effect on much larger weather systems. That's why it's especially tough to make accurate forecasts more than a few days in advance.

## Is there a way to tell how close a storm is?

Lightning and thunder always go together, because thunder is the sound that results from lightning. Lightning bolts are close to 30,000 degrees Celsius (54,000 degrees Fahrenheit), so the air in the atmosphere that they zip through becomes superheated and quickly expands. That sound of expansion is called thunder, and on average it's about 120 decibels (a chainsaw is 125, for reference). Sometimes you can see lightning but not hear the thunder, but that's only because the lightning is too far away for you to hear it. Because light travels faster than sound, you always see lightning before hearing it.



Lightning occurs most often in hot, summer-like climates

### Where are you most likely to get hit by lightning?

Generally lightning strikes occur most often during the summer. So the place where lightning strikes occur the most is a place where summer-like weather prevails year-round: Africa. Specifically, it's the village of Kifuka in the Democratic Republic of Congo. Each year, it gets more than 150 lightning strikes within one square kilometre. Roy Sullivan didn't live in Kifuka but he still managed to get struck by lightning seven separate times while working as a park ranger in the Shenandoah National Park in the USA. The state in which he lived – Virginia – does have a high incidence of lightning strikes per year, but since Sullivan spent his job outdoors in the mountains, his risk was greater due to his exposure.

#### 1. Start the count

When you see a flash of lightning, start counting. A stopwatch would be the most accurate way.

#### 2. Five seconds

The rule is that for every five seconds, the storm is roughly 1.6 kilometres (one mile) away.

#### 3. Do the maths

Stop counting after the thunder and do the maths. If the storm's close, take the necessary precautions.

### CAN IT REALLY RAIN ANIMALS?

Animals have fallen from the sky before, but it's not actually 'raining' them. More likely strong winds have picked up large numbers of critters from ponds or other concentrations – perhaps from tornadoes or downspouts – then moved and deposited them. Usually the animals in question are small and live in or around water for a reason.

### DOES FREAK WEATHER CONFUSE WILDLIFE?

A short period of unseasonable weather isn't confusing for wildlife, but a longer one can be. For example, warm weather in winter may make plants bloom too early or animals begin mating long before spring actually rolls around.

### IS THE 'RED SKY AT NIGHT, SHEPHERD'S DELIGHT' SAYING TRUE?

The rest of the proverb is, 'Red sky at morning, shepherd's warning'. A red sky means you could see the red wavelength of sunlight reflecting off clouds. At sunrise, it was supposed to mean the clouds were coming towards you so rain might be on the way. If you saw these clouds at sunset, the risk had already passed. Which is 'good' or 'bad' is a matter of opinion.

### WHAT ARE SNOW DOUGHNUTS?

Snow doughnuts, also known as rollers, are a rare natural phenomenon. If snow falls in a clump, gravity can pull it down over itself as it rolls. Normally it would collapse, but sometimes a hole forms. Wind and temperature also play key roles.

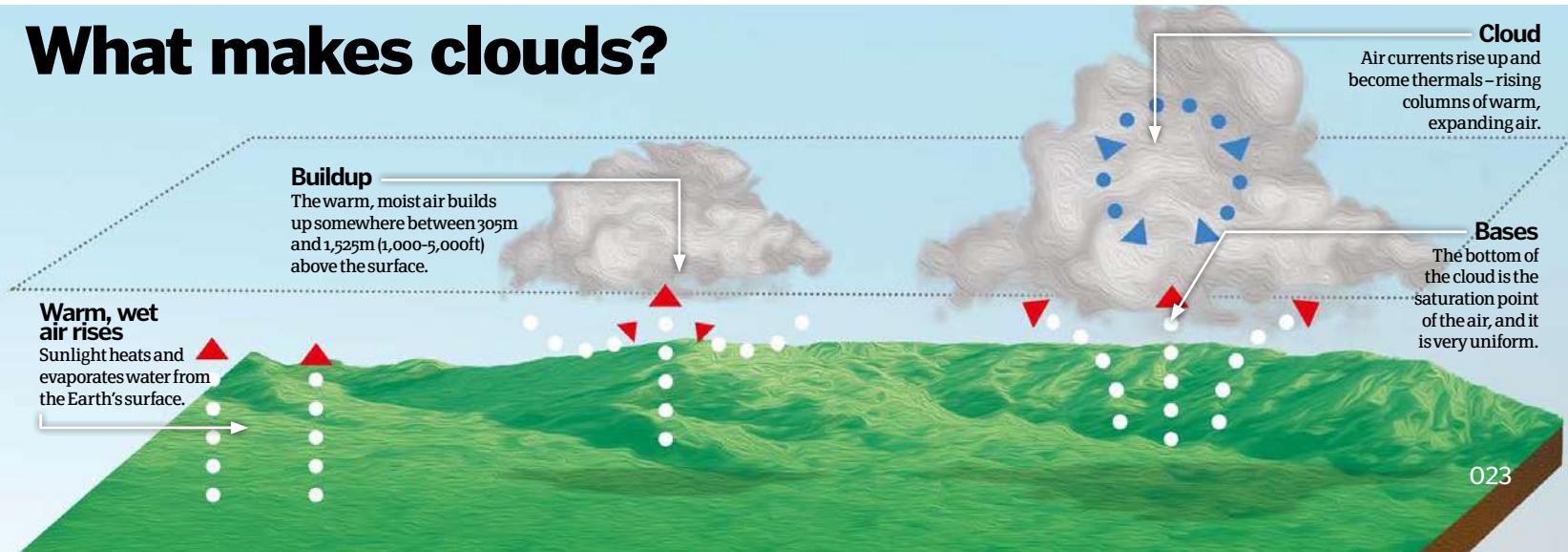
What is the fastest wind ever recorded, not in a tornado?

407km/h [253mph]  
Gusts recorded during Cyclone Olivia in 1996

## Is it possible to stop a hurricane?

We can't control the weather... or can we? Some scientists are trying to influence the weather through cloud seeding, or altering the clouds' processes by introducing chemicals like solid carbon dioxide (aka dry ice), calcium chloride and silver iodide. It has been used to induce rainfall during times of drought as well as to prevent storms.

## What makes clouds?



Cloud

Air currents rise up and become thermals – rising columns of warm, expanding air.

Bases

The bottom of the cloud is the saturation point of the air, and it is very uniform.



## WHAT ARE KATABATIC WINDS?

From the Greek for 'going downhill', a katabatic wind is also known as a drainage wind. It carries dense air down from high elevations, such as mountain tops, down a slope thanks to gravity. This is a common occurrence in places like Antarctica's Polar Plateau, where incredibly cold air on top of the plateau sinks and flows down through the rugged landscape, picking up speed as it goes. The opposite of katabatic winds are called anabatic, which are winds that blow *up* a steep slope.

## DOES IT EVER SNOW IN AFRICA?

Several countries in Africa see snow – indeed, there are ski resorts in Morocco and regular snowfall in Tunisia. Algeria and South Africa also experience snowfall on occasion. It once snowed in the Sahara, but it was gone within 30 minutes. There's even snowfall around the equator if you choose to count the snow-topped peaks of mountains in that area.

## WHAT COLOUR IS LIGHTNING?

Usually lightning is white, but it can be every colour of the rainbow. There are a lot of factors that go into what shade the lightning will appear, including the amount of water vapour in the atmosphere, whether it's raining and the amount of pollution in the air. A high concentration of ozone, for example, can make lightning look blue.

## WHY DO SOME CITIES HAVE THEIR OWN MICROCLIMATE?

Some large metropolises have microclimates – that is, their own small climates that differ from the local environment. Often these are due to the massive amounts of concrete, asphalt and steel; these materials retain and reflect heat and do not absorb water, which keeps a city warmer at night. This phenomenon specifically is often known as an urban heat island. The extreme energy usage and pollution in large cities may also contribute to this.

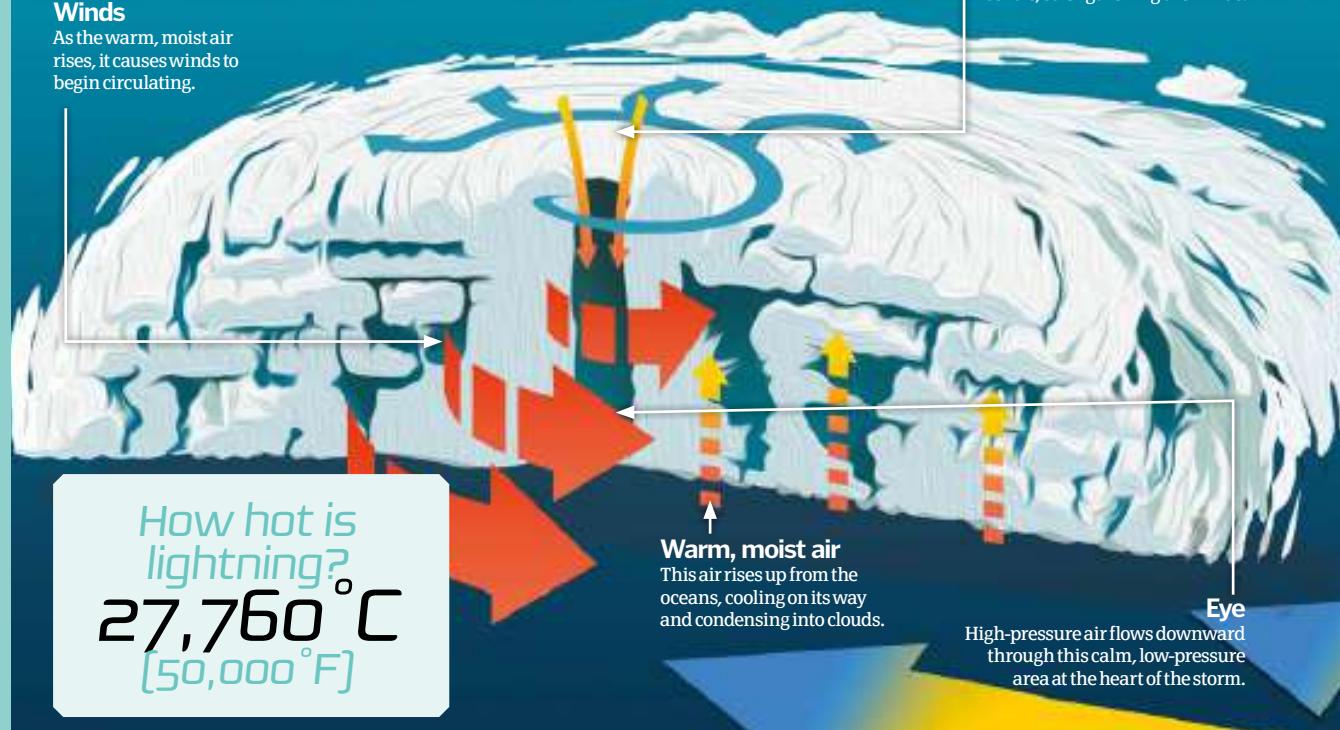
# What causes hurricanes?

Depending on where they start, hurricanes may also be known as tropical cyclones or typhoons. They always form over oceans around the equator, fuelled by the warm, moist air. As that air rises and forms clouds, more warm, moist air moves into the area of lower pressure below. As the cycle continues, winds begin rotating and pick up speed. Once it hits 119 kilometres (74 miles) per hour, the storm is

officially a hurricane. When hurricanes reach land, they weaken and die without the warm ocean air. Unfortunately they can move far inland, bringing a vast amount of rain and destructive winds. People sometimes cite 'the butterfly effect' in relation to hurricanes. This simply means something as small as the beat of a butterfly's wing can cause big changes in the long term.

### Winds

As the warm, moist air rises, it causes winds to begin circulating.



It's difficult to know exactly what would happen to our weather if the Moon were destroyed, but it wouldn't be good. The Moon powers Earth's tides, which in turn influence our weather systems. In addition, the loss of the Moon would affect the Earth's rotation – how it spins on its axis. The presence of the Moon creates a sort of drag, so its loss would probably speed up the rotation, changing the length of day and night. In addition it would alter the tilt of the Earth too, which causes the changes in our seasons. Some places would be much colder while others would become much hotter. Let's not neglect the impact of the actual destruction, either; that much debris would block out the Sun and rain down on Earth, causing massive loss of life. Huge chunks that hit the ocean could cause great tidal waves, for instance.

**What are the odds of getting hit by lightning in a lifetime?**

**1 in 300,000**

### Cool, dry air

Cooled, dry air at the top of the system is sucked down in the centre, strengthening the winds.

## Why do clouds look different depending on their height?

### Altocumulus

Patchy clumps and layers make up this mid-level cloud. It often precludes storms.

### Cirrus

These thin, hair-like clouds form at, or above, 5,000m (16,500ft) and may arrive in advance of thunderstorms.

### Stratocumulus

These are low, lumpy clouds usually bringing a drizzling rain. They may hang as low as 300m (1,000ft).

### Altocumulus

These very thin, grey clouds can produce a little rain, but they may grow eventually into stratus clouds.

### Cumulus

These vertically building clouds are puffy, with a base sub-2,000m (6,550ft).

### Cumulonimbus

This vertical, dense cloud heaps upon itself and often brings heavy thunderstorms.

### Stratus

These low-lying, horizontal, greyish clouds often form when fog lifts from the land.



*How many volts are in a lightning flash?*  
**1 billion**

## Why are you safer inside a car during an electrical storm?

People used to think the rubber tyres on a car grounded any lightning that may strike it and that's what kept you safe. However, you're safer in your car during an electrical storm because of the metal frame. It serves as a conductor of electricity, and channels the lightning away into the ground without impacting anything – or anyone – inside; this is known as a Faraday cage. While it is potentially dangerous to use a corded phone or other appliances during a storm because lightning can travel along cables, mobile or cordless phones are fine. It's also best to avoid metallic objects, including golf clubs.

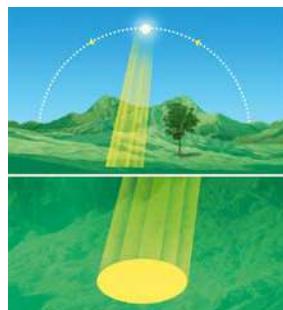
© SPL

## How does the Sun cause the seasons?

Seasons are caused by the Earth's revolution around the Sun, as well as the tilt of the Earth on its axis. The hemisphere receiving the most direct sunlight experiences spring and summer, while the other experiences autumn and winter. During the warmer months, the Sun is higher in the sky, stays above the horizon for longer, and its rays are more direct. During the cooler half, the Sun's rays aren't as strong and it's lower in the sky. The tilt causes these dramatic differences, so while those in the northern hemisphere are wrapping up for snow, those in the southern hemisphere may be sunbathing on the beach.

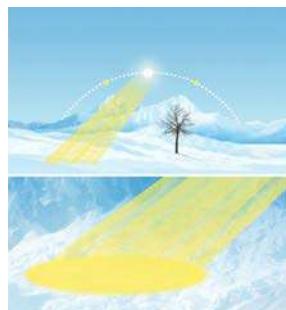
### SUMMER

The Sun is at its highest point in the sky and takes up more of the horizon. Its rays are more direct.



### WINTER

The Sun is at its lowest point in the sky and there is less daylight. The rays are also more diffuse.



## What is ball lightning?

This mysterious phenomenon looks like a glowing ball of lightning, and floats near the ground before disappearing, often leaving a sulphur smell. Despite many sightings, we're still not sure what causes it.



## What causes giant hailstones?

Put simply, giant hailstones come from giant storms – specifically a thunderstorm called a supercell. It has a strong updraft that forces wind upwards into the clouds, which keeps ice particles suspended for a long period. Within the storm are areas called growth regions; raindrops spending a long time in these are able to grow into much bigger hailstones than normal.

### WHAT IS CLOUD IRISESCE?

This happens when small droplets of water or ice crystals in clouds scatter light, appearing as a rainbow of colours. It's not a common phenomenon because the cloud has to be very thin, and even then the colours are often overshadowed by the Sun.

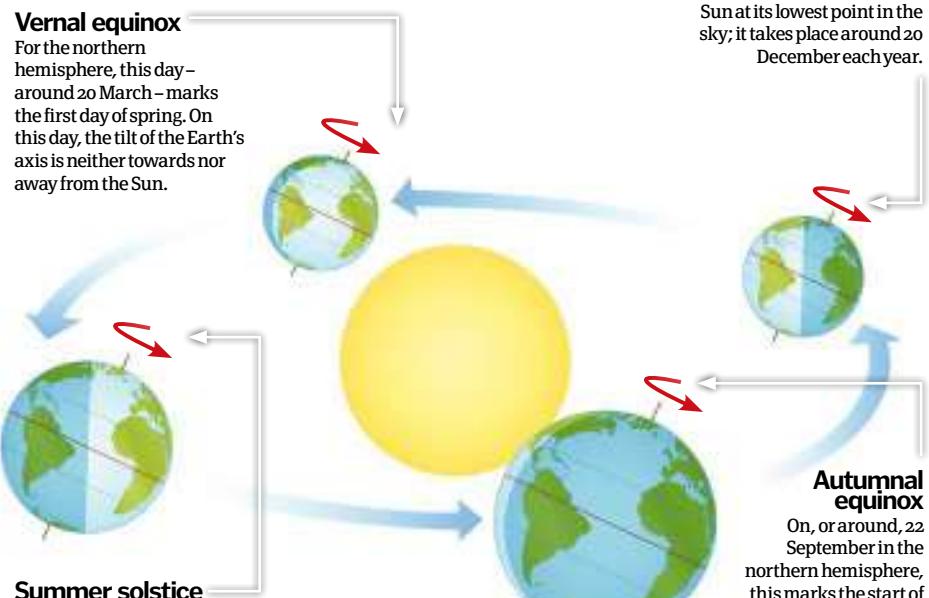
### WHAT DO WEATHER SATELLITES DO?

The GOES (Geostationary Operational Environmental Satellite) system is run by the US National Environmental Satellite, Data, and Information Service (NESDIS). The major element of GOES comprises four different geosynchronous satellites (although there are also other geo-satellites either with other uses now or that have been decommissioned).

The whole system is used by NOAA's National Weather Service for forecasting, meteorological research and storm tracking. The satellites provide continuous views of Earth, giving data on air moisture, temperature and cloud cover. They also monitor solar and near-space activities like solar flares and geomagnetic storms.

### Winter solstice

The winter solstice marks the beginning of winter, with the Sun at its lowest point in the sky; it takes place around 20 December each year.



### Summer solstice

During the summer solstice, around 20 June, the Sun is at its highest, or northernmost, point in the sky.

### Autumnal equinox

On, or around, 22 September in the northern hemisphere, this marks the start of autumn. The tilt of the Earth's axis is neither towards nor away from the Sun.



## HOW LONG DOES A RAINBOW LAST?

There is no set rule for the duration a rainbow will last. It all depends on how long the light is refracted by water droplets in the air (eg rain, or the spray from a waterfall).

## WHY DOES THE AIR SMELL FUNNY AFTER RAIN HAS FALLEN?

This scent comes from bacteria in the soil. Once the earth dries, the bacteria (called actinomycetes) release spores. Rainfall kicks these spores up into the air, and then the moist air disperses them. They tend to have a sweet, earthy odour.

## HOW MUCH RAIN CAN A HURRICANE BRING?

The average hurricane, with a radius of about 1,330 kilometres (825 miles), can dump as much as  $21.3 \times 10^{15}$  cubic centimetres ( $1.3 \times 10^{15}$  cubic inches) of water in one day. That's enough rain to fill up 22 million Olympic-size swimming pools!

## WHAT ARE DROUGHTS AND HEAT WAVES?

Droughts are about an extreme lack of water, usually due to lower than average rainfall, and last for months or even years. There's no set definition of a heat wave, but it typically means higher than average temperatures for several consecutive days. Both can lead to crop failures and fatalities.

## WHY ARE RAINBOWS ARCH-SHAPED?

Rainbows are arched due to the way sunlight hits raindrops. It bends as it passes through because it slows during this process. Then, as the light passes out of the drop, it bends again as it returns to its normal speed.

## How hot was the hottest day in history?

**58°C [136°F]**

Recorded on 13 September 1922 in Al Aziziyah, Libya



## What's the difference between rain, sleet and snow?

When it comes to precipitation, it's all about temperature. When the air is sufficiently saturated, water vapour begins to form clouds around ice, salt or other cloud seeds. If saturation continues, water droplets grow and merge until they become heavy enough to fall as rain. Snow forms when the air is cold enough to freeze supercooled water droplets – lower than -31 degrees Celsius (-34 degrees Fahrenheit) – then falls. Sleet is somewhere in between: it starts as snow but passes through a layer of warmer air before hitting the ground, resulting in some snow melting.

## What are gravity wave clouds?

Gravity waves are waves of air moving through a stable area of the atmosphere. The air might be displaced by an updraft or something like mountains as the air passes over. The upward thrust of air creates bands of clouds with empty space between them. Cool air wants to sink, but if it is buoyed again by the updraft, it will create additional gravity wave clouds.

## Why is it so quiet after it snows?

It's peaceful after snowfall as the snow has a dampening effect; pockets of air between the flakes absorb noise. However, if it's compacted snow and windy, the snow might actually reflect sound.

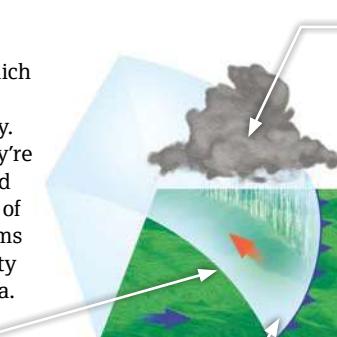
## What is a weather front?

A weather front is the separation between two different masses of air, which have differing densities, temperature and humidity.

On weather maps, they're delineated by lines and symbols. The meeting of different frontal systems causes the vast majority of weather phenomena.

### Wedge

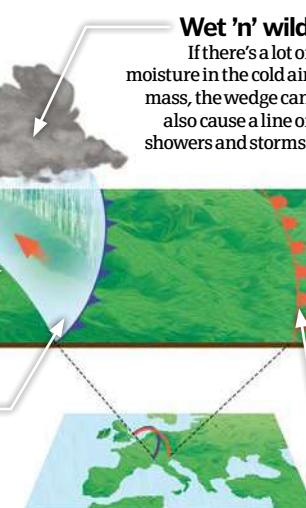
As cold air is denser, it often 'wedges' beneath the warm air. This lift can cause wind gusts.



**Wet 'n' wild**  
If there's a lot of moisture in the cold air mass, the wedge can also cause a line of showers and storms.

### Cold front

Cold fronts lie in deep troughs of low pressure and occur where the air temperature drops off.



### Thunderstorms

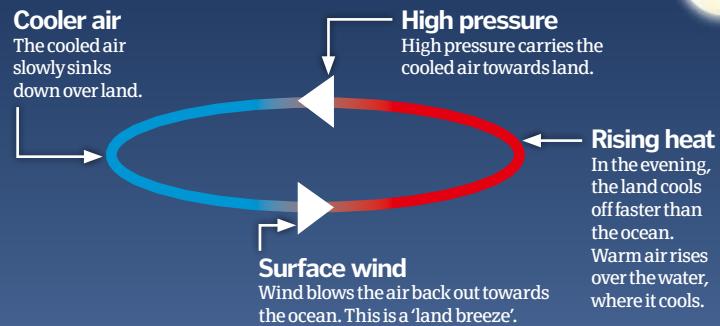
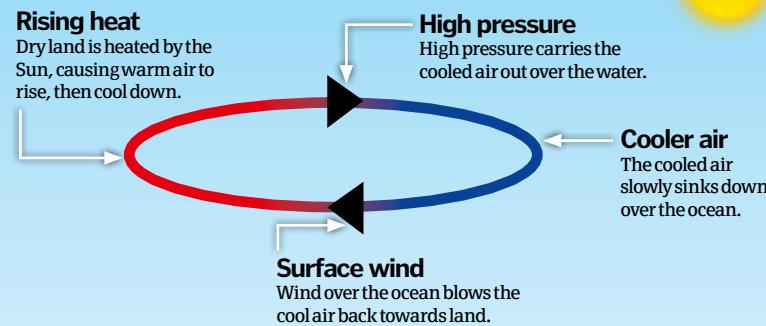
Unstable masses of warm air often contain stratiform clouds, full of thunderstorms.

**Fog**  
Fog often comes before the slow-moving warm front.

### Warm front

Warm fronts lie in broad troughs of low pressure and occur at the leading edge of a large warm air mass.

# What is a sea breeze?



## What is the eye of a storm?

The eye is the calm centre of a storm like a hurricane or tornado, without any weather phenomena. Because these systems consist of circular, rotating winds, air is funnelled downward through the eye and feeds back into the storm itself.



## What are red sprites and blue jets?

These are both atmospheric and electrical phenomena that take place in the upper atmosphere, and are also known as upper-atmosphere discharge. They take place above normal lightning: blue jets occur around 40-50 kilometres (25-30 miles) above the Earth, while red sprites are higher at 50-100 kilometres (32-64 miles). Blue jets happen in cone shapes above thunderstorm clouds, and are not related to lightning. They're blue due to ionised emissions from nitrogen. Red sprites can appear as different shapes and have hanging tendrils. They occur when positive lightning goes from the cloud to the ground.

## Does lightning ever strike in the same place twice?

Yes, lightning often strikes twice in the same location. If there's a thunderstorm and lightning strikes, it's just as likely to happen again. Many tall structures get struck repeatedly during thunderstorms, such as New York City's famed Empire State Building or NASA's shuttle launch pad in Cape Canaveral, Florida.

*How cold was the coldest day in recorded history?*  
**-89 °C [-129 °F]**  
*Recorded on 21 July 1983 at Vostok II Station, Antarctica*

## Why does the Sun shine?

The Sun is a super-dense ball of gas, where hydrogen is continually burned into helium (nuclear fusion). This generates a huge deal of energy, and the core reaches 15 million degrees Celsius (27 million degrees Fahrenheit). This extreme heat produces lots of light.

## WHY ARE CLOUDS FLUFFY?

Fluffy-looking clouds – the big cotton-ball ones – are a type called cumulus. They form when warm air rises from the ground, meets a layer of cool air and moisture condenses. If the cloud grows enough to meet an upper layer of freezing air, rain or snow may fall from the cloud.

## WHAT'S IN ACID RAIN?

Acid rain is full of chemicals like nitrogen oxide, carbon dioxide and sulphur dioxide, which react with water in the rain. Much of it comes from coal powerplants, cars and factories. It can harm wildlife and also damage buildings.

## WHY CAN I SEE MY BREATH IF IT'S COLD?

Your breath is full of warm water vapour because your lungs are moist. When it's cold outside and you breathe out, that warm vapour cools rapidly as it hits the cold air. The water molecules slow down, begin to change form, and bunch up together, becoming visible.

## WHAT IS THE GREEN FLASH YOU SEE AS THE SUN SETS SOMETIMES?

At sunsets (or indeed sunrises), the Sun can occasionally change colour due to refraction. This can cause a phenomenon called green flash. It only lasts for a second or two so can be very tricky to spot.

# How do jet streams work?

They're a vital component in regulating global weather, but what do jet streams actually do?

**J**et streams are currents of fast-moving air found high in the atmosphere of some planets. Here on Earth, when we refer to 'the jet stream', we're typically talking about either of the polar jet streams. There are also weaker, subtropical jet streams higher up in the atmosphere, but their altitude means they have less of an effect on commercial air traffic and the weather systems in more populated areas.

The northern jet stream travels at about 161-322 kilometres (100-200 miles) per hour from west to east, ten kilometres (six miles) above the surface in a region of the atmosphere known as the tropopause (the border between the troposphere and the stratosphere). It's created by a combination of our planet's rotation, atmospheric heating from the Sun and the Earth's own heat from its core creating temperature differences and, thus, pressure gradients along which air rushes.

In the northern hemisphere, the position of the jet stream can affect the weather by bringing in or pushing away the cold air from the poles. Generally, if it moves south, the weather can turn wet and windy; too far south and it will become much colder than usual. The reverse is true if the jet stream moves north, inducing drier and hotter weather than average as warm air moves in from the south.

In the southern hemisphere, meanwhile, the jet stream tends to be weakened by a smaller temperature contrast created by the greater expanse of flat, even ocean surface, although it can impact the weather in exactly the same way as the northern jet stream does.

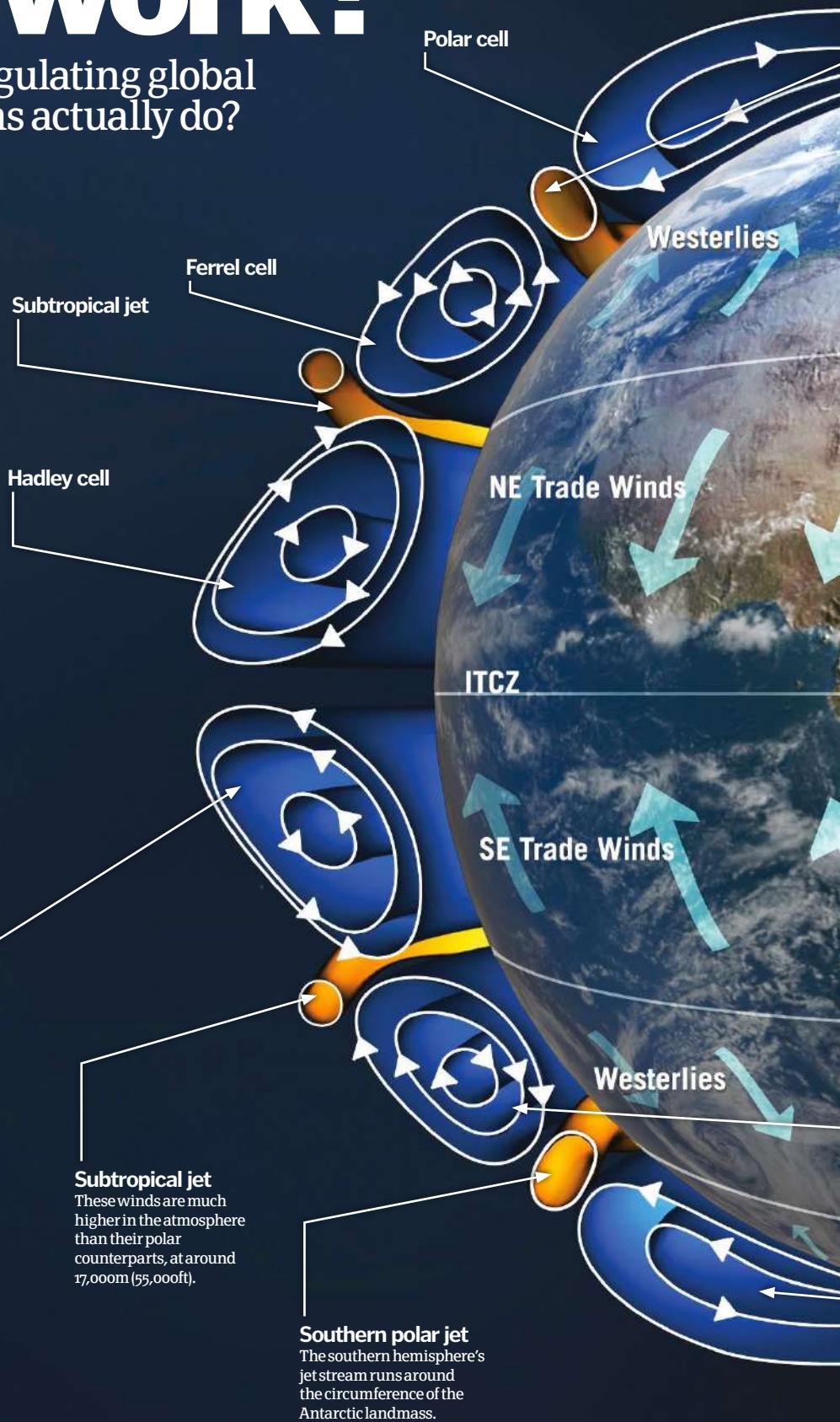
**Hadley cell**  
This atmospheric cell is partly responsible for the deserts and rainstorms in the tropics.

## Winds of change

Currents in the jet stream travel at various speeds, but the wind is at its greatest velocity at the centre, where jet streaks can reach speeds as fast as 322 kilometres (200 miles) per hour. Pilots are trained to work with these persistent winds when flying at jet stream altitude, but wind shear is a dangerous phenomenon that they must be ever vigilant of. This is a sudden, violent change in wind direction and speed that can happen in and around the jet stream, affecting even winds at ground level. A sudden gust like this can cause a plane that's taking off/landing to crash, which is why wind shear warning systems are equipped as standard on all commercial airliners.

## Earth's jet streams

*A closer look at some of the invisible phenomena that play a major role in our planet's climate*

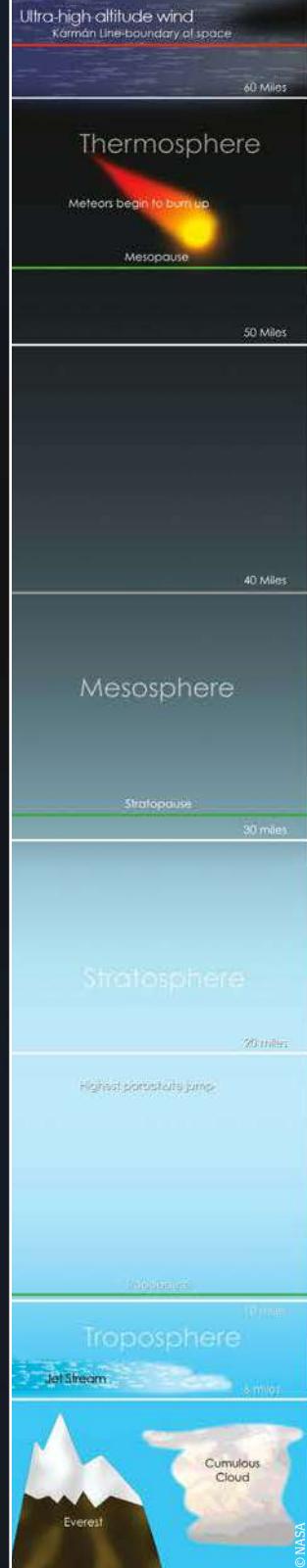


**DID YOU KNOW?** Mount Everest is so high that its 8,848m (29,029ft) summit actually sits in a jet stream



## Where is the jet stream?

A layer-by-layer breakdown of the Earth's atmosphere and whereabouts the jet stream sits





# Predicting the weather

Discover the method that helps us prepare for the elements, come rain or shine

**T**he weather affects us all, every day. From governing the difference between life and death, to providing a conversation topic to fill awkward silences at a party, it is an ever-present and ever-changing part of life. This means that predicting it accurately is a hugely important task.

In the UK, the Met Office is responsible for weather monitoring and prediction. Before a forecast can be put together, measurements from thousands of data recorders across the world are

collected and analysed. Every day, around 500,000 observations are received, including atmospheric measurements from land and sea, satellites, weather balloons and aircraft. But, this is still not enough to represent the weather in every location.

To fill in the gaps, the data is assimilated. This combines current data with what is expected, to provide the best estimate of the atmospheric conditions. To produce an accurate forecast, the data has to be fed into a supercomputer that creates

a numerical model of the atmosphere. The process involves many complex equations, and the Met Office's IBM supercomputer can do more than 1,000 trillion calculations a second, running an atmospheric model with a million lines of code.

Forecasters can use this data and techniques such as nowcasting – using estimates of current weather speed and direction – to predict the weather in the hours ahead. For longer range forecasts, further computer models are relied upon.

## 1 Data collection

Data from receivers all over the world is transmitted to a variety of hubs such as the World Meteorological Association in Switzerland.

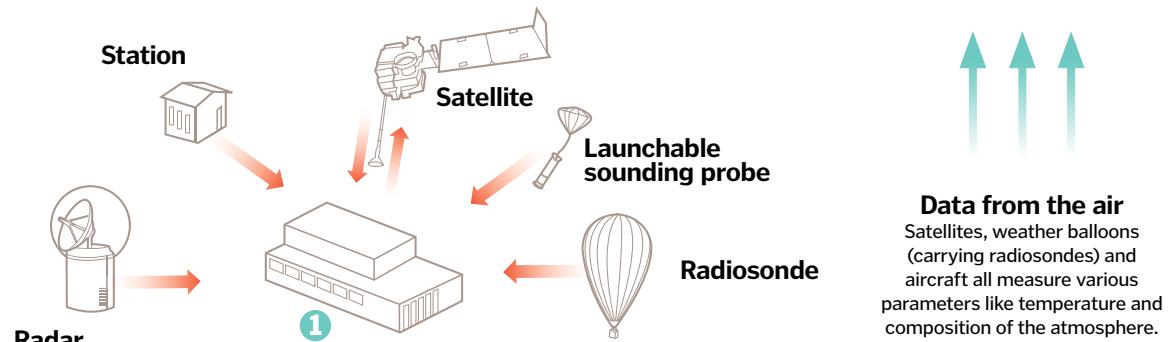
## 2 Land-based data

Instruments on land measure temperature, atmospheric pressure, humidity, wind speed and direction, cloud cover, visibility and precipitation.

## 3 Meteorological station

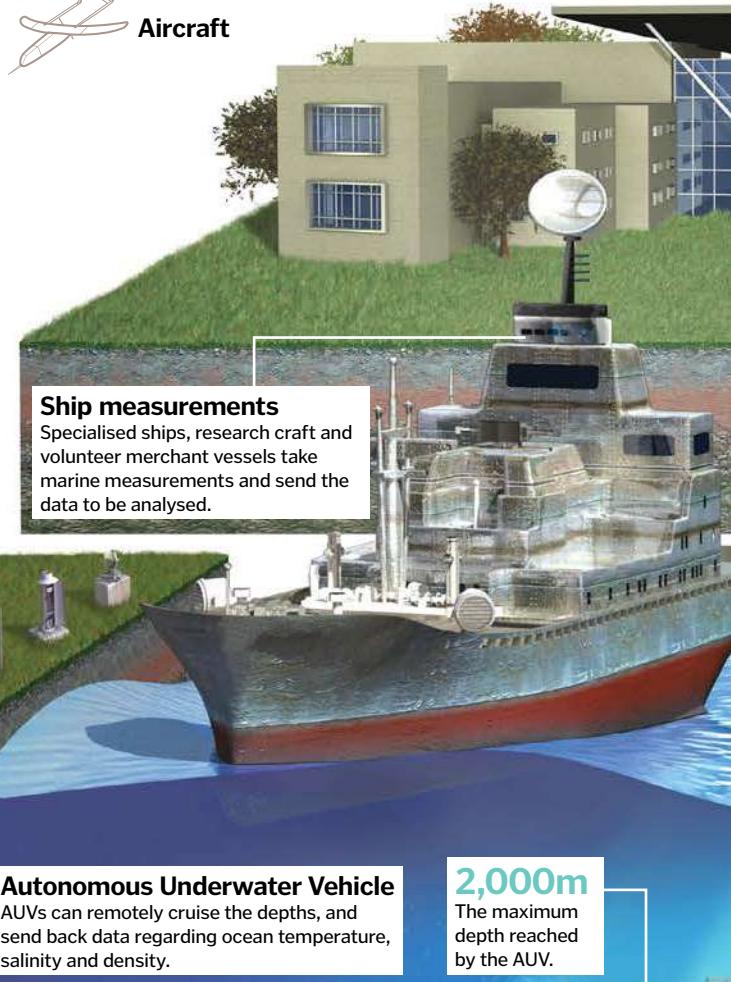
Small weather stations take local readings, with thermometers for temperature, hygrometers for humidity and barometers to measure atmospheric pressure.

Thousands of small weather stations across the world feed data back to meteorological hubs



## Data from the sea

Ships and buoys measure water temperature, salinity, density and reflected sunlight, as well as wind speed and wave data.



#### 4 Radiosonde

This small instrument is attached to a helium or hydrogen balloon and takes airborne measurements of pressure, temperature and humidity.

**15,000m**

The altitude reached by a radiosonde.

4



#### Meteorological aircraft

Data comes from either specialist meteorological planes, or from the automatic recordings of commercial flights.

**13,000m**

The altitude reached by G-IV aircraft, which drop sounding probes towards the ground.

**10,000m**

The altitude at which specialist meteorological aircraft can reach.



#### Hurricane Hunters

These modified Lockheed P-3 Orion aircraft, which are equipped with state-of-the-art instruments, and a highly sensitive Doppler radar.

**4,270m**

The altitude reached by the P-3 aircraft.

**Doppler radar**



**Jet G-IV**



**Parachutes prolong airtime**

**Radiosonde sends information to base**

**365m**

The altitude reached by an aerosonde drone.

**Aerosonde**

This unmanned research craft is capable of sampling and recording weather data swiftly and accurately.

**Current model**

**Scale: 12km per slide**

**Experimental model**

**Scale: 1.3km per slide**

**Strongest winds**

**“Every day, around 500,000 observations are received from land and sea”**

#### Meteorological centres

All of the data recorded is assimilated in these centres, as well as being analysed and distributed for more local predictions.

**Navigation lights**

**Anemometer**

**Data transmitter**

**Solar panel**

#### Weather buoys

Either tethered or free-floating, buoys are furnished with instruments to take meteorological measurements where ships can't or don't go.

#### Maritime sounding probes

Dropped from aircraft into the sea, these probes are often called 'dropsondes' and can sample and transmit data back to base.

#### Radar station

Radar is used in meteorology to measure the intensity with which rain, snow, sleet or hail is falling.



Capable of breaking down the resistance of air, lightning is a highly visible discharge of electricity capable of great levels of destruction. But how is it formed?

Intense upthrust of volcanic particles can help generate lightning

**L**ightning occurs when a region of cloud attains an excess electrical charge, either positive or negative, that is powerful enough to break down the resistance of the surrounding air. This process is typically initiated by a preliminary breakdown within the cloud between its high top region of positive charge, large central region of negative charge and its smaller lower region of positive charge.

The different charges in the cloud are created when water droplets are supercooled within it to freezing temperatures and then collide with ice crystals. This process causes a slight positive charge to be transferred to the smaller ice crystal particles and a negative one to the larger ice-water mixture, with the former rising to the

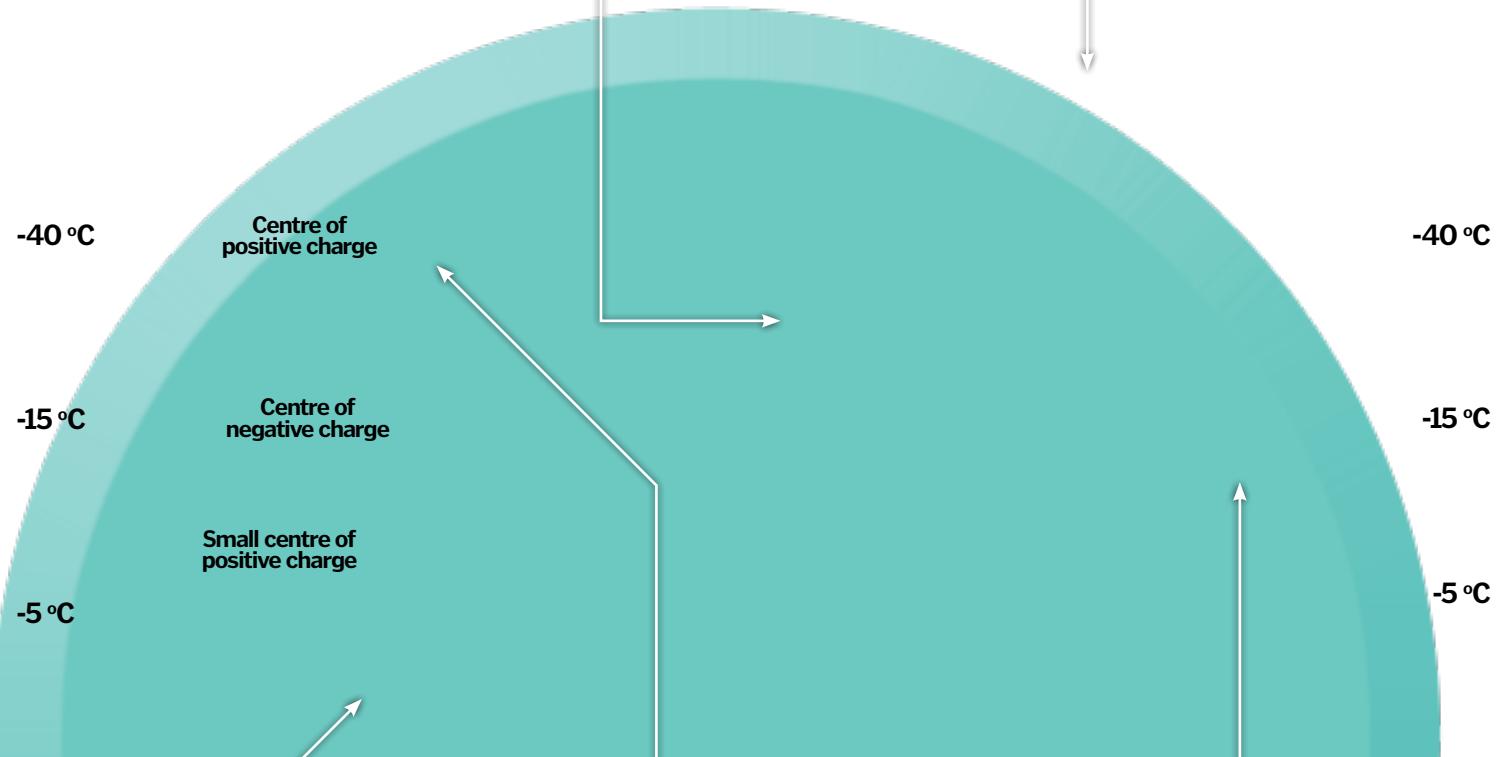
top on updrafts and the latter falling to the bottom under the effect of gravity. The consequence of this is gradual separation of charge between the upper and lower parts of the cloud.

This polarisation of charges forms a channel of partially ionised air – ionised air is that in which neutral atoms and molecules are converted to electrically charged ones – through which an initial lightning stroke (referred to as a 'stepped leader') propagates down through towards the ground. As the stepped leader reaches the Earth, an upwards connecting discharge of the opposing polarity meets it and completes the connection, generating a return stroke that due to the channel now being the path of least

resistance, returns up through it to the cloud at one-third the speed of light and creating a large flash in the sky.

This leader-return stroke sequence down and up the ionised channel through the air commonly occurs three or four times per lightning strike, faster than the human eye is capable of perceiving. Furthermore, due to the massive potential difference between the charge areas – often extending from an incredible ten to 100 million volts – the return stroke can hold currents up to 30,000 amperes and reach heights of 30,000°C (54,000°F). Typically the leader stroke reaches the ground in just ten milliseconds and the return stroke reaches the instigating cloud in 100 microseconds.

# Explaining the formation of lightning

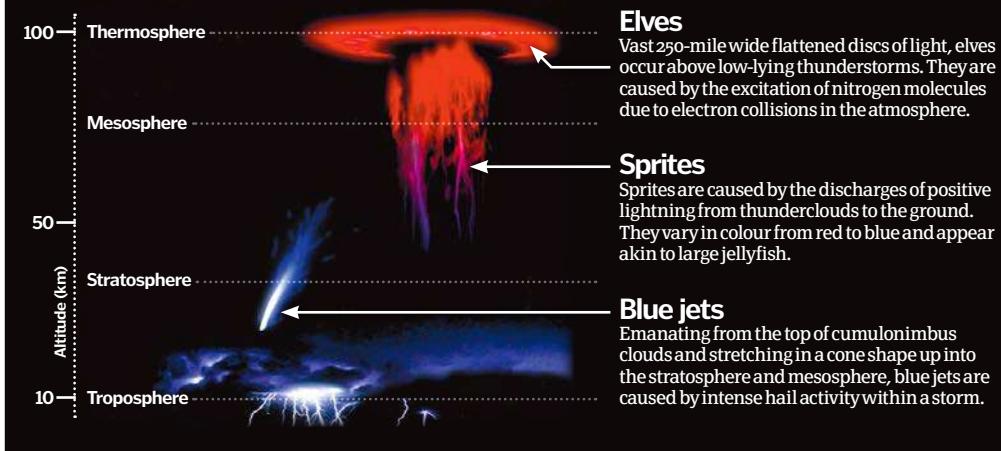


Lightning, however, does not just occur between clouds (typically cumulonimbus or stratiform) and the ground, but also between separate clouds and even intra-cloud. In fact, 75 per cent of all lightning strikes worldwide are cloud-to-cloud or intra-cloud, with discharge channels forming between areas of positive and negative charges between and within them. In addition, much lightning occurs many miles above the Earth in its upper atmosphere (see 'Atmospheric lightning' boxout), ranging from types that emanate from the top of clouds, to those that span hundreds of miles in width.

Despite the high frequency of lightning strikes and their large amount of contained energy, current efforts by the scientific community to harvest its power have been fruitless. This is mainly caused by the inability of modern technology to receive and store such a large quantity of energy in such a short period of time, as each strike discharges in mere milliseconds. Other issues preventing lightning's use as an energy source include its sporadic nature – which while perfectly capable of striking the same place twice, rarely does – and the difficulties involved in converting high-voltage electrical power delivered by a strike into low-voltage power that can be stored and used commercially.

## Atmospheric lightning

Unseen apart from by satellites, a major part of the world's annual lightning is generated in Earth's upper atmosphere.





# Lightning types

Far from uniform, lightning is an unpredictable phenomenon

## Bead lightning

A type of cloud-to-ground lightning where the strike seems to break up into smaller, super-bright sections (the beads), lasting longer than a standard discharge channel.

Frequency: Rare

## Ribbon lightning

Only occurring in storms with high cross winds and multiple return strokes, ribbon lightning occurs when each subsequent stroke is blown to the side of the last, causing a visual ribbon effect.

Frequency: Quite rare

## Staccato lightning

A heavily branched cloud-to-ground lightning strike with short duration stroke and incredibly bright flash.



Frequency: Common

## Sheet lightning

A generic term used to describe types of cloud-to-cloud lightning where the discharge path of the strike is hidden from view, causing a diffuse brightening of the surrounding clouds in a sheet of light.



Frequency: Common

## Megalightning

A term commonly used when referring to upper-atmospheric types of lightning. These include sprites, blue jets and elves (see 'Atmospheric lightning' boxout) and occur in the stratosphere, mesosphere and thermosphere.

Frequency: Frequent

## Ball lightning

Considered as purely hypothetical by meteorologists, ball lightning is a highly luminous, spherical discharge that according to few eyewitnesses last multiple seconds and can move on the wind.

Frequency: Very rare



# Lightning hotspots

A look at some of the most dangerous places to be when lightning strikes

## Danger zone

Ten per cent of all people struck by lightning were in Florida at the time.



## Multiple strikes

The Empire State Building is struck 24 times per year on average. It was once struck eight times in 24 minutes.



## Global hotspot

The small village of Kifuka is the most struck place on Earth, with 158 strikes per square kilometre per year.

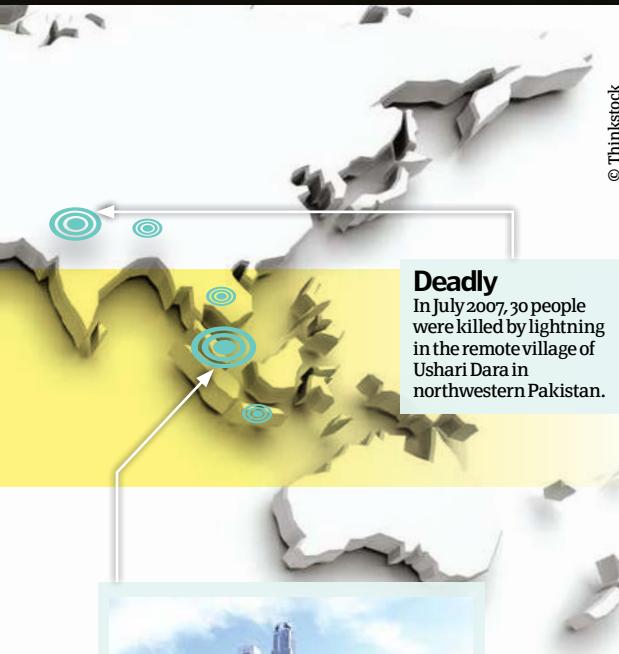


# What are the chances?

The odds of being hit by lightning aren't as slim as you think...

1 in 300,000

The chance of you getting struck by lightning is one in 300,000. Which, while seeming quite unlikely, did not stop US park ranger Roy Sullivan from being struck a world record seven times during his lifetime.



## in comparison...

### 1 in 14,000,000

The chance of winning the lottery in the UK is one in 14 million. That is over 45 times as unlikely as being struck.

### 1 in 11,000,000

Flying on a single-trip commercial air flight inflicts you to a one in 11 million chance of being killed in an accident.

### 1 in 12,000,000

The odds of getting hit by lightning are 40 times more likely than the chance of dying from Mad Cow Disease in the UK.

### 1 in 8,000

In order to get better odds, go out in your car. Over 3,000 people are killed every day on roads worldwide.

# What happens when you get struck by lightning?

The parts of the body that feel the effect if struck by lightning

When a human is hit by lightning, part of the strike's charge flows over the skin – referred to as external flashover – and part of it goes through them internally. The more of the strike that flows through, the more internal damage it causes. The most common organ affected is the heart, with the majority of people who die from a strike doing so from cardiac arrest. Deep tissue destruction along the current path can also occur, most notably at the entrance and exit points of the strike on the body. Lightning also causes its victims to physically jump, which is caused by the charge contracting the muscles in the body instantaneously.

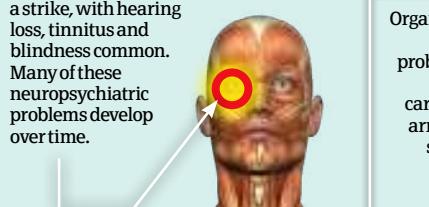
Burns are the most visible effect of being struck by lightning, with the electrical charge heating up any objects in contact with the skin to incredible levels, causing them to melt and bond with the human's skin. Interestingly, however, unlike industrial electrical shocks – which can last hundreds of milliseconds and tend to cause widespread burns all over the body – lightning-induced burns tend to be centred more around the direct point of contact, with a victim's head, neck and shoulders most affected.

Post-strike side-effects of being struck by lightning range from amnesia, seizures, motor control damage, hearing loss and tinnitus, through blindness, sleep disorders, headaches, confusion, tingling and numbness. Further, these symptoms do not always develop instantaneously, with many – notably neuropsychiatric problems (vision and hearing) – developing over time.



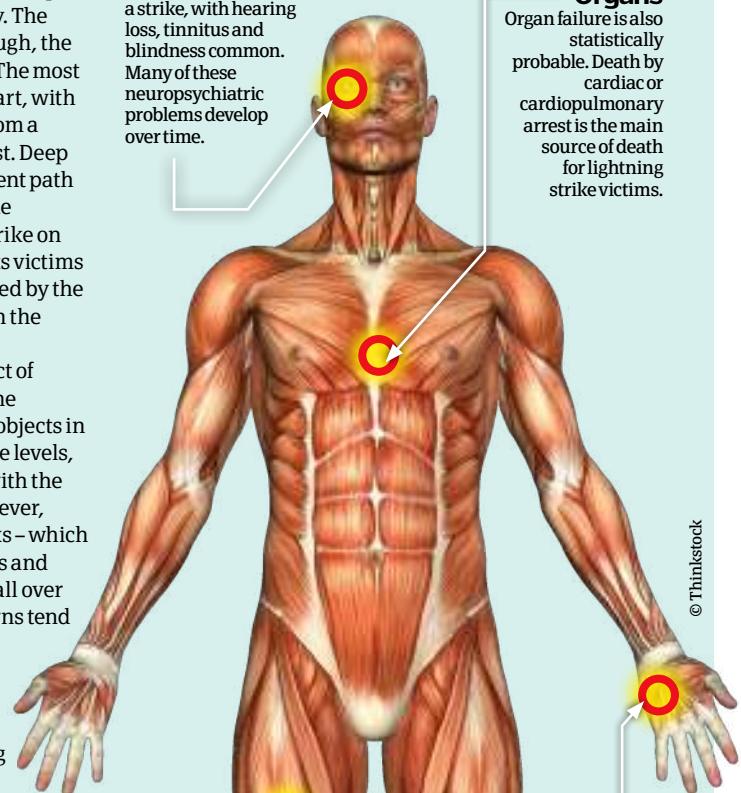
### Audio visual

Eyes and ears are commonly affected by a strike, with hearing loss, tinnitus and blindness common. Many of these neuropsychiatric problems develop over time.



### Organs

Organ failure is also statistically probable. Death by cardiac or cardiopulmonary arrest is the main source of death for lightning strike victims.



© Thinkstock

### Skin

When struck a portion of the strike's charge flows over the skin, while the rest flows through the body internally. Skin burns and hair loss are common side effects as well as the bonding of worn fabrics.

### Muscles

Muscles contract instantly on strike, causing the victim to jump and suffer muscular seizures.

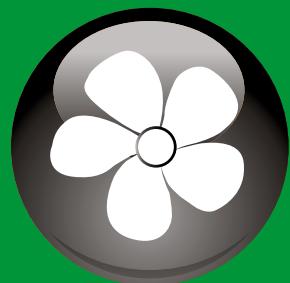


### Body tissue

Deep tissue destruction is common along the current path, which courses through the body from cranium to feet.

### Nervous system

Motor control damage is common, often permanently affecting muscle and limb movement, neural circuitry and motor planning and execution decisions.



# PLANTS & ORGANISMS



*"Cacti have developed optimal forms for retention of internal water supplies... this allows them to store vast quantities of water for elongated periods"*



## How cacti survive 050

- 038 How plants work**  
The incredible life cycle of a plant explained
- 042 Identifying leaves**  
Identify leaves of different trees with our guide
- 044 Poisonous plants**  
Discover which dangerous plants to avoid
- 046 The life of trees**  
Discover how trees grow and why you can't live without them
- 050 How do cacti live?**  
The survival methods of these prickly flowers
- 051 How are plants cloned?**  
How identical copies of plants benefit us



044  
Poisonous plants



042  
Identifying leaves



A sunflower head comprises up to 2,000 tiny individual flowers



# How plants work

Could you stay put in your birthplace for hundreds of years, surviving off whatever happens to be around?

Truly, it's not easy being green. But plants not only survive, they thrive all over the globe, without the benefit of muscles, brains or personalities. It's a good thing they do: plants head up nearly all food chains, pump out the oxygen we breathe, hold off erosion and filter pollutants out of the atmosphere. Over the past 3.5 billion years, they've diversified into an estimated 320,000-430,000 separate species, with more coming to light every year.

All this stems from one neat trick: harnessing the Sun's energy to power a built-in food factory. Through this process, called photosynthesis, plants combine carbon dioxide with water to create carbohydrates that they use to grow and reproduce. The earliest plants, similar to today's algae, didn't do much other than photosynthesis. They floated around in the ocean, soaking up water and rays and

reproducing asexually. Then, around 500 million years ago, plants evolved to live on land, to obtain the power boost of more abundant sunlight. The first landlubber plants still needed to stay wet all over, however, so they were confined to perpetually damp areas. Today's mosses, liverworts, and hornworts have the same limitations.

Things got more exciting 90 million years later, when plants went vascular. Vascular plants have tissue structures that can distribute water and nutrients absorbed by one part of the body to the rest of the body. Instead of spending its days soaking in a puddle, a vascular plant can grow roots down into the ground to soak up water and minerals while sending shoots up into the dry air, topped with leaves that soak up sunshine to power the food factory. This feature allows vascular plants to evolve to a larger size.

Plants can store this food in their roots, in the form of root tubers, like carrots and sweet potatoes. Above ground, vascular plants protect themselves and retain their water supply with a waxy, waterproof covering called cuticle. Cuticle makes plants hearty enough to reach high into the air or spread far along the ground.

Plants grow at meristems, areas with cells that are capable of division – that is, making new cells. Hormones control this cell division to grow particular forms, like leaves, as well as controlling the direction of growth, guided by what the plant 'senses'. Based on the settling of starch grains that indicate the direction of gravity, the growth hormone auxin drives stems to grow up towards the sky and roots to grow down towards water. Then, plants actually turn leaves toward the Sun. Triggered by light-sensitive cells that effectively 'see' light, the

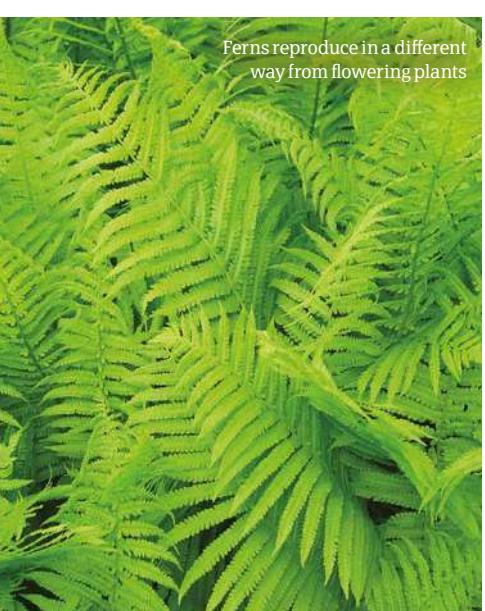
hormone auxin causes more cells to grow on the dimmer side of a stem, making the stem and attached leaf bend towards sunlight. Similarly, vines automatically curl when they come across a larger plant, causing them to wrap and climb.

Plants switch sexual orientation every generation. Each sporophyte generation produces male and female spores, which asexually yield male and female plants. In this gametophyte generation, males produce sperm and females produce eggs, which join up to create new sporophyte plants. Typically, the sporophyte generation is a large, familiar plant, while the gametophyte generation is tiny. For example, pollen is tiny male plants in the gametophyte generation. The tiny males and females produce an embryo, or seed.

When you can't walk, spreading your seed requires a little more creativity. For example, flowering plants attract insects with nectar, and then coat their legs with pollen to carry to the next plant. Plants also develop tasty fruits around plant seeds to entice animals to swallow seeds, and then defecate those seeds miles away.

Plants enrich every corner of human life, even beyond food and oxygen. From invaluable herbs – plants with medicinal or flavour value – to towering trees made from woody tissue, our original go-to construction material, plants prop up our civilisation. High-five one today.

Ferns reproduce in a different way from flowering plants



### 1. The carpel

The female centrepiece of a flower comprises the ovary and a slender neck called the style, which has a sticky top called a stigma.

### 6. The ovary

The ovary includes multiple compartments called ovules, each housing one gametophyte – technically, a tiny female plant.

### 7. The embryo sac

In each ovule, cells divide to form an embryo sac, which includes an egg, two nuclei and an opening for the pollen tube.

### 10. The embryo

Through cell division, the zygote feeds off the endosperm.

### 8. The pollen tube

When the pollen tube reaches and penetrates the ovule, it releases the two sperm cells into an embryo sac.

### 4. Prothallus

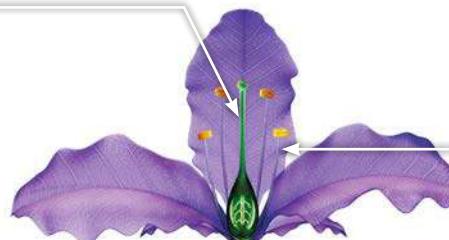
Each spore grows into a type of gametophyte called a prothallus. This is much bigger than the gametophytes in flowering plants.

### 3. Spores

When enough spores form, they burst open the pod and disperse.

### 2. Sporangia

Inside these hard pods on the underside of fern fronds, spore cells multiply.



## Life cycle of a flowering plant

### 2. The stamen

The flower's male members include this stalk-like filament, topped with the pollen-producing anther.

### 3. The petals

Flower petals are like a neon sign designed to attract insects that come for the free nectar, then unintentionally carry pollen to other flowers.

### 4. Gametophytes

Inside each anther, gametophytes – technically microscopic male plants – are encased in pollen grain capsules. Each includes two sperm cells and a tube cell.

### 5. The stigma

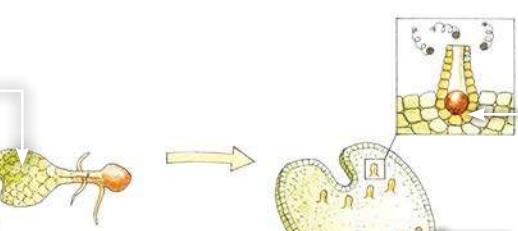
Pollen grains stick to the stigma at the tip of the carpel, and produce a pollen tube down the style and ovary.

### 11. The seed

The casing surrounding the ovule hardens around the embryo, to form a seed. When it has ample warmth, moisture, and oxygen (typically in the spring), the seed germinates – that is, begins to grow into an adult plant.

### 9. The zygote

One of the sperm cells fertilises the egg, creating a zygote. The two nuclei and the other sperm cell fuse to form a food supply called endosperm.



## Life cycle of a fern

### 6. Archegonia

Sperm from another prothallus fertilises the egg inside the archegonia, to form a zygote.

### 5. Mature gametophyte

The prothallus grows both a female sex organ (the archegonia) and a male sex organ (the antherida), which produces sperm.

### 7. Young fern

The zygote grows into a young fern, and the prothallus structure withers away.



## Most unusual plants



### The sensitive plant

Touch a leaf on the sensitive plant, also known as *mimosa pudica*, and an electrical current activates sudden water loss, causing leaves to drop abruptly. This imitation of an animal scares pests away.



© Bharath han 2009

### Myrmecophytes

Many species, collectively known as myrmecophytes, have evolved to be ideal homes for ant colonies. In return, the ants viciously attack any threats to the plant.



### Sumatran corpse flower

This flower can grow to be 0.9m (3ft) wide and 11 kilograms (24 pounds). It mimics the smell of rotting meat in order to attract carrion-eating insects, which then spread its pollen.

### Snowdonia hawkweed

This Welsh flower is possibly the world's rarest plant. Botanists thought it extinct in the early-Fifties, but in 2002 it made a surprise reappearance near Bethesda.

## Plant plumbing: How transport works

Internal transportation systems in plants move water, food and other nutrients between roots, stems and leaves. This system is the key adaptation that allowed plants to evolve elaborate shapes and towering forms.

### Upper epidermis

The waxy cuticle on the epidermis keeps the plant from drying out.

### Palisade mesophyll

These cells are rich in chloroplasts, which are integral in photosynthesis.

### Xylem vessel

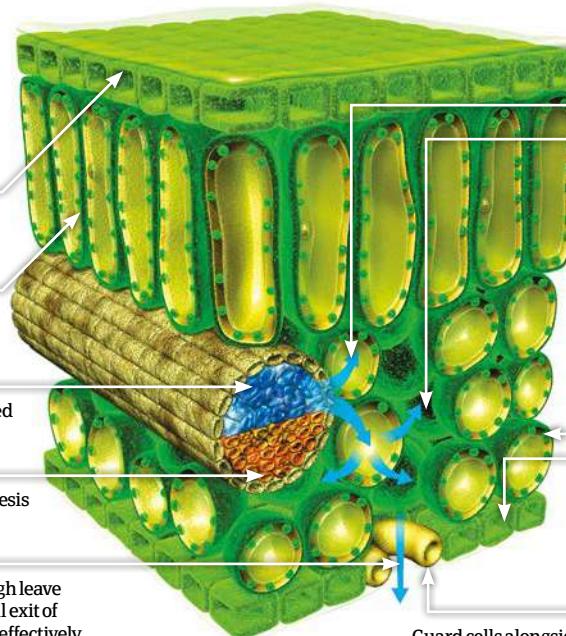
These vessels carry water, with dissolved minerals, from the roots to leaves.

### Phloem vessel

These carry food created in photosynthesis from leaves to the rest of the plant.

### Diffusion

This water vapour exits the plant through leaf openings called stomata. This continual exit of water creates negative pressure, which effectively pulls water up the xylem from the roots.



### Movement of water

Water moves from the xylem vessels, which run from the roots to leaves, into the mesophyll cells.

### Evaporation

Water along the walls of the mesophyll cells evaporates, forming water vapour.

### Spongy mesophyll

Mesophyll cells fit together to form most of the tissue in a leaf.

### Lower epidermis

The lower epidermis can be thinner than the upper epidermis, since it doesn't get direct sunlight.

### Stoma

Guard cells alongside each stoma (pore in the leaf) open when sunlight and humidity are high.



Flower stigmas come in various shapes



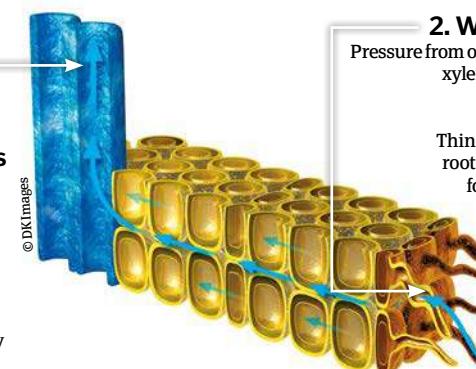
Insects seeking nectar pick up pollen on their legs

## The root of it: How absorption works

Roots soak up water through osmosis – the drive for water to move through a cell membrane from a less concentrated solution to a more concentrated solution, in order to achieve equilibrium. Cells in roots have a higher concentration than the surrounding water in the soil, so the water flows into the root.

### 3. Water enters the stem

Water continues flowing through the xylem, up into the above-ground stem, helped along by negative pressure in the leaves, created by evaporating water.



### 2. Water enters xylem

Pressure from osmosis pushes water into xylem vessels in the root core.

### 1. Root hairs

Thin hairs extending from the root increase the surface area for osmosis, and so handle most water absorption.

# Inside the food factory: How photosynthesis works

In Greek, photosynthesis means 'putting together' (synthesis) using 'light' (photo), and that's a decent summary of what it's all about. However, photosynthesis doesn't actually turn light into food, as you sometimes hear; it's the power source for a chemical reaction that turns carbon dioxide and water into food.

The energy of light photons temporarily boosts the electrons in pigment molecules to a higher energy level. In other words, they generate an electrical charge. The predominant pigment in plants – chlorophyll – primarily absorbs blue, red, and violet light, while reflecting green light (hence, the green colour). In some leaves, chlorophyll breaks down in the autumn, revealing secondary pigments that reflect yellows, reds, and purples. Pigments are part of specialised organelles called chloroplasts, which transfer the energy of excited electrons in pigments to molecules and enzymes that carry out the photosynthesis chemical reaction.



## Harnessing sunlight

Chlorophyll and other pigments absorb energy of light photons from the Sun.

## Nucleus

The cell nucleus houses genetic instructions (DNA) and relays instructions to the rest of the cell.

## Breaking water down

The energy from light breaks water molecules down into hydrogen and oxygen.

## Adding carbon dioxide

Plants get all the CO<sub>2</sub> they need from the air. CO<sub>2</sub> combines with hydrogen to make glucose, a simple sugar.

## Expelling oxygen

The oxygen from the water isn't necessary to make food, so the plant releases it through pores called stomata.

## Vacuole

Among other things, this organelle contains water that helps maintain the turgor pressure that keeps plants erect.

## Making food

Through additional reactions, the plant converts glucose into a range of useful compounds. Sucrose acts as plant fuel, starches store energy for later, protein aids cell growth, and cellulose builds cell walls.

## Chloroplast

These are the engines for photosynthesis. A typical leaf palisade cell includes up to 200 chloroplasts.

© DK Images



## How much of the planet is covered by forest?

40 million sq km (15,444,100 sq miles), or a third of the Earth's land area, is covered by forests.

- 1 34% Rest of the world
- 2 20% Russian Federation
- 3 12% Brazil
- 4 8% US
- 5 8% Canada
- 6 5% China
- 7 4% Australia
- 8 3% Democratic Republic of Congo
- 9 2% India
- 10 2% Indonesia
- 11 2% Peru



## Bunchberry dogwood

This shrub holds the 'fastest plant' record. When its flower opens, stamens fling out like a catapult, propelling pollen at 800 times the g-force astronauts experience.



## Parachute flowers

The different species of parachute flower have long flower tubes lined with inward pointing hairs that temporarily hold insects trapped, to ensure they end up covered in pollen before exiting.



## Welwitschia mirabilis

This so-called 'living fossil' plant of the Namib desert in Africa grows only two leaves, over hundreds of years. They grow continuously, however, and can extend more than 4 metres (13 feet).



## Flypaper plants

Also known as butterworts, these plants are coated in super-sticky digestive enzymes that absorb nutrients from all manner of bugs that happen to get trapped.



# See the leaves for the trees

Yew willow become an expert at identifying leaves with our handy guide



## Maple

You might recognise this leaf from Canada's national flag. A maple tree's leaves usually have between three and nine lobes, and are arranged opposite one another on the branches.



## Ash

Ash leaves form in pairs; each central stem will bear nine to 13 leaflet pairs with one leaf at the tip. All leaves are pointed and toothed, and have tiny hairs on their lower surface.



## Plantain

These form in a rosette formation and range from five to thirty centimetres (two to 12 inches) in length. Generally, they are egg-shaped and are often hairless.



## Oak

There are two main types of oak tree, the sessile oak and the pedunculate oak (which has a shorter stem). Oak leaves are used by the US Army as a rank symbol.



## Willow

Willow leaves tend to be long and thin and will alternate along the stem. As they mature, they lose many of their minute hairs and become a duller green on top, while the underside remains silver.



## Alder

Each alder leaf will have six to eight pairs of veins which are quite sunken in appearance. These leaves remain on the tree until quite late in the year.



## Lime

Lime leaves are generally heart-shaped and in an alternate arrangement. The margin is made up of tiny teeth and the underside has prominent veins protruding from its surface.



## Hazel

Hazel leaves are almost completely round other than the section nearest the tip which is slightly pointed. It has a noticeable toothed edge with a hairy underside and stalk.



## Acacia

Acacia leaves are classed as compound pinnate, as they form in pairs with a single leaflet at the end of the branch. In hotter countries, acacia stalks flatten to protect the leaves from intense sunlight.



## Horse chestnut

Each horse chestnut leaf is narrow at its base but broadens out towards the tip. All the leaves have a central vein that is quite prominent, along with a serrated margin.



## Elm

Elm leaves are characterised by their asymmetrical base and the way they taper to a sudden point at the top. They also have a jagged, saw-toothed edge and a rough, hairy surface.



## Hawthorn

Hawthorn leaves have a simple structure and tend to have a similar sized breadth and width. Many hawthorn hedges were planted during the Tudor period to mark farmland boundaries.



## Sycamore

Sycamore leaves always have five distinctive lobes, along with five veins radiating from the base into the lobes. The leaf edge is quite ragged, with multiple rounded teeth all the way around it.



## Clover

The clover leaf is typically trifoliate (has three leaflets) but the current world record is an incredible 56 leaflets! One in ten thousand have four leaflets instead of three, which many consider to be lucky.



## Water lily

Water lilies are famous for their round, waxy-coated leaves which sit on top of long stalks. The leaves protrude out of their freshwater habitat and float on the surface.



## Cottonwood

Cottonwood leaves have an unusual triangular shape. Their petiole (which attaches each leaf blade to the stem) is a very important feature; it is flattened sideways to enable the leaf to move in a certain way in windy conditions.



## Rowan

The rowan tree (mountain ash), has compound leaves with up to 21-paired leaflets. Each has a serrated edge with small teeth and grey hairs underneath.



## Strawberry

Strawberry plant leaves typically have three lobes and are dark green in colour. The leaf edge is jagged and curves upwards as the leaf unfurls, before flattening as they grow.



## Fern

Fern branches are known as fronds which consist of a stalk with leaf-like growths sprouting from it. These leafy growths have a feathery structure and are commonly known as pinnae.



## Celandine

The leaves of the greater celandine are heavily lobed and are a grey-green colour. Celandine leaf is used to form a herbal supplement to treat digestive disorders.



## Bramble

Each bramble branch will have between five and seven leaflets growing from it, all of which have a particularly jagged edge. An army of sharp thorns grow on each stem, providing protection.



## Red oak

Red oak leaves differ to those of white oaks in their lobe shape – red oaks have pointed lobes rather than round ones. Most red oaks have large leaves that are at least ten centimetres (four inches) in size.



## Lilac

Lilac tree leaves are characterised by their tear-drop shape which is rounded near the stem with a long 'drip tip' at the other end. They are dark green, and grow up to almost 13 centimetres (five inches) in length.



## White poplar

White poplar leaves typically have a number of irregular lobes, however, those nearest the branch tips have three to five deep lobes. All leaves have a green upper surface and thick hair on the underside.



## Elder

Each leaf is longer than it is wide, with a sharply toothed edge and small hairs on the underside. The leaves usually feature between five and seven leaflets in an opposite arrangement.



## Dog rose

Between five and seven dog rose leaves form in compound pairs along each branch. These leaves are usually hairless and dark green in colour, with a slightly lighter underside.



## Beech

Beech leaves have a simple structure and appear alternately along the branches. When they first form, the leaves are light green and have small hairs. Once they mature, they darken and lose the small hairs.



## Stinging nettle

The stinging nettle plant has fine toothed, tapered leaves, which can grow to 15 centimetres (5.9 inches) in length. These almost heart-shaped leaves can be eaten when cooked and work well as a spinach substitute.



## London plane

Similar in style to the leaves of a maple or sycamore, leaves of the London plane are lobed and veined, with a darker top surface. Before they fall in the autumn, they turn a distinctive yellow or orange colour.

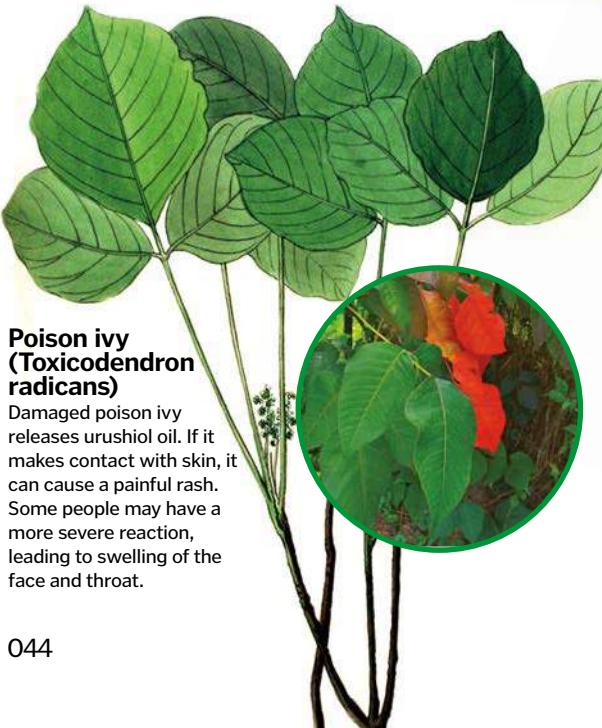


# Poisonous plants

They may look harmless, but some species of flora can be fatal

There are lots of delicious and nutritious plants growing in nature, but there are also some that you should definitely keep off your plate. Even the most tasty-looking berries or succulent leaves can contain deadly poisons, while other plants are even harmful just to touch. It is thought that these poisonous plants evolved to contain their lethal toxins as a form of self-defence, poisoning the animals and humans who dare to eat or touch them to stop them from coming back for more. However, some plants affect animals and humans in different ways. For example, it takes just four castor seeds to kill a human, but 80 to kill a duck.

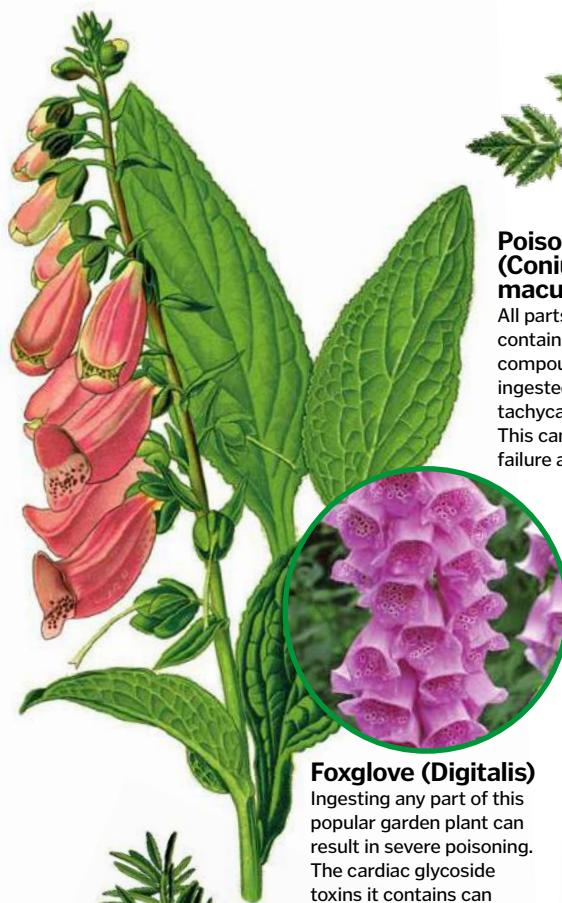
To make matters even more confusing, it is sometimes the case that only part of the plant is poisonous. For example, the stalks of rhubarb plants are great in a crumble, but eating the leaves, which contain oxalic acid, can cause nausea and vomiting. In other cases, toxic plants can actually benefit your health, as it has been discovered that the poisonous taxane alkaloids found in Yew trees contain chemicals that can be used to stop cancer cells from forming. Don't go munching on its leaves though, as you'll be left feeling rather unwell.



**Poison ivy**  
(*Toxicodendron radicans*)

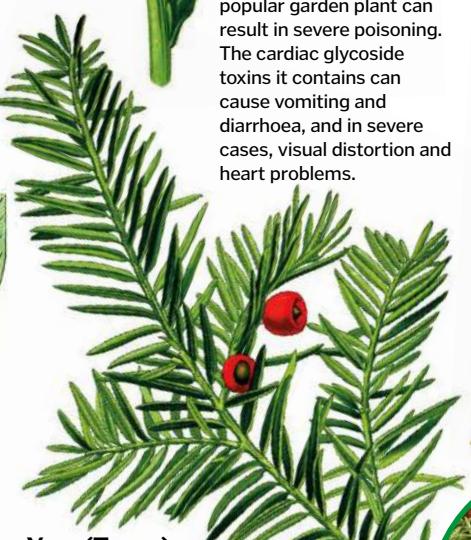
Damaged poison ivy releases urushiol oil. If it makes contact with skin, it can cause a painful rash. Some people may have a more severe reaction, leading to swelling of the face and throat.

*"It takes four castor seeds to kill a human, but 80 to kill a duck"*



**Foxglove** (*Digitalis*)

Ingesting any part of this popular garden plant can result in severe poisoning. The cardiac glycoside toxins it contains can cause vomiting and diarrhoea, and in severe cases, visual distortion and heart problems.



**Yew** (*Taxus*)

Highly poisonous taxane alkaloids can be found in all but the flesh of the berries of this evergreen tree. Once ingested, there are sometimes no symptoms until the victim collapses and dies.



**Poison hemlock**  
(*Conium maculatum*)

All parts of poison hemlock contain toxic alkaloid compounds that, when ingested, can cause seizures, tachycardia and paralysis. This can lead to respiratory failure and ultimately death.



**Golden chain**  
(*Laburnum*)

Laburnum seeds are carried in pods, which look like pea pods, but shouldn't be eaten. The plant contains the poisonous alkaloid cytisine, which can be deadly in large doses.





**Castor oil plant  
(*Ricinus communis*)**

The seeds of this plant contain ricin, a toxic chemical that stops proteins being made in cells. Once ingested, they can cause vomiting, diarrhoea, seizures and eventually organ failure.

**False hellebore  
(*Veratrum viride*)**

Also called Indian poke, all parts of the plant contain steroidal alkaloids, which cause nausea and vomiting when eaten. It lowers blood pressure and slows heart rate.

**Monkshood  
(*Aconitum*)**

Simply brushing up against this plant can be dangerous, as the aconitine toxin it contains can be absorbed through the skin. This can cause paralysis of the heart and airways, and eventually death.



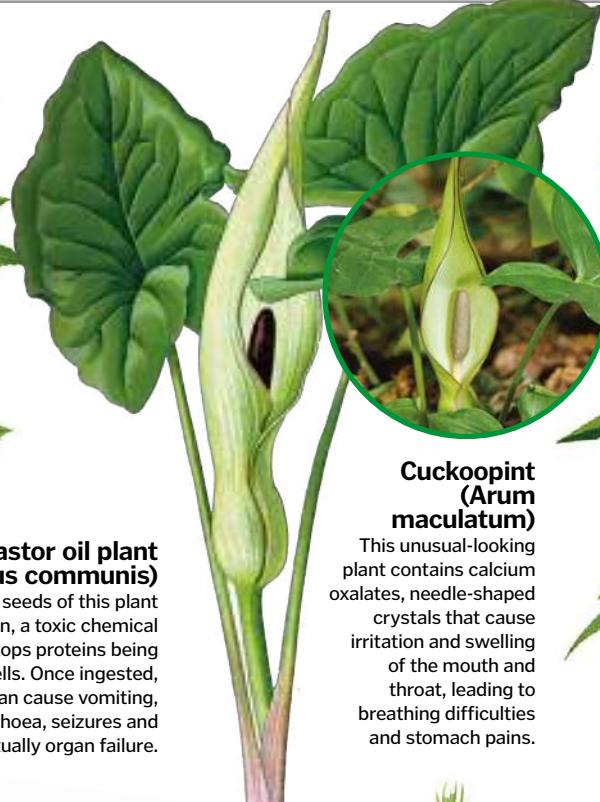
## How to avoid poisonous plants

When outdoors, it is always best to be cautious around unfamiliar plants, and avoid touching or eating them unless you know they are safe. If you do have a reaction or become unwell after touching or ingesting a plant, visit a doctor straight away and take a piece of the plant with you. This will help them to identify it and determine the best cause of treatment. For many poisonous plants, there is no antidote available, but if caught early enough, the symptoms can usually be treated to avoid serious health problems or death.

When gardening, wear gloves to prevent dangerous plants from coming into contact with your skin



When outdoors, it is always best to be cautious around unfamiliar plants, and avoid touching or eating them unless you know they are safe. If you do have a reaction or become unwell after touching or ingesting a plant, visit a doctor straight away and take a piece of the plant with you. This will help them to identify it and determine the best cause of treatment. For many poisonous plants, there is no antidote available, but if caught early enough, the symptoms can usually be treated to avoid serious health problems or death.



**Cuckoopint  
(*Arum maculatum*)**

This unusual-looking plant contains calcium oxalates, needle-shaped crystals that cause irritation and swelling of the mouth and throat, leading to breathing difficulties and stomach pains.



**Oleander (*Nerium oleander*)**

This ornamental, evergreen shrub contains cardiac glycoside, which can prove fatal if ingested directly or if food has come into contact with the plant, and it can irritate the skin when touched.



**Deadly nightshade  
(*Atropa belladonna*)**

Its ripe berries may look appetising, but eating just two is enough to kill a child. The plant contains tropane alkaloids, which cause hallucinations and attack the nervous system.

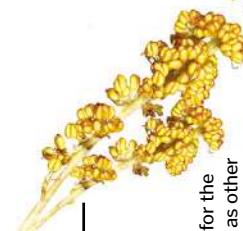


There are around 600 species of oak tree, found across the Northern Hemisphere

# The life of trees

From seed to forest giant, discover how trees grow and why you can't live without them

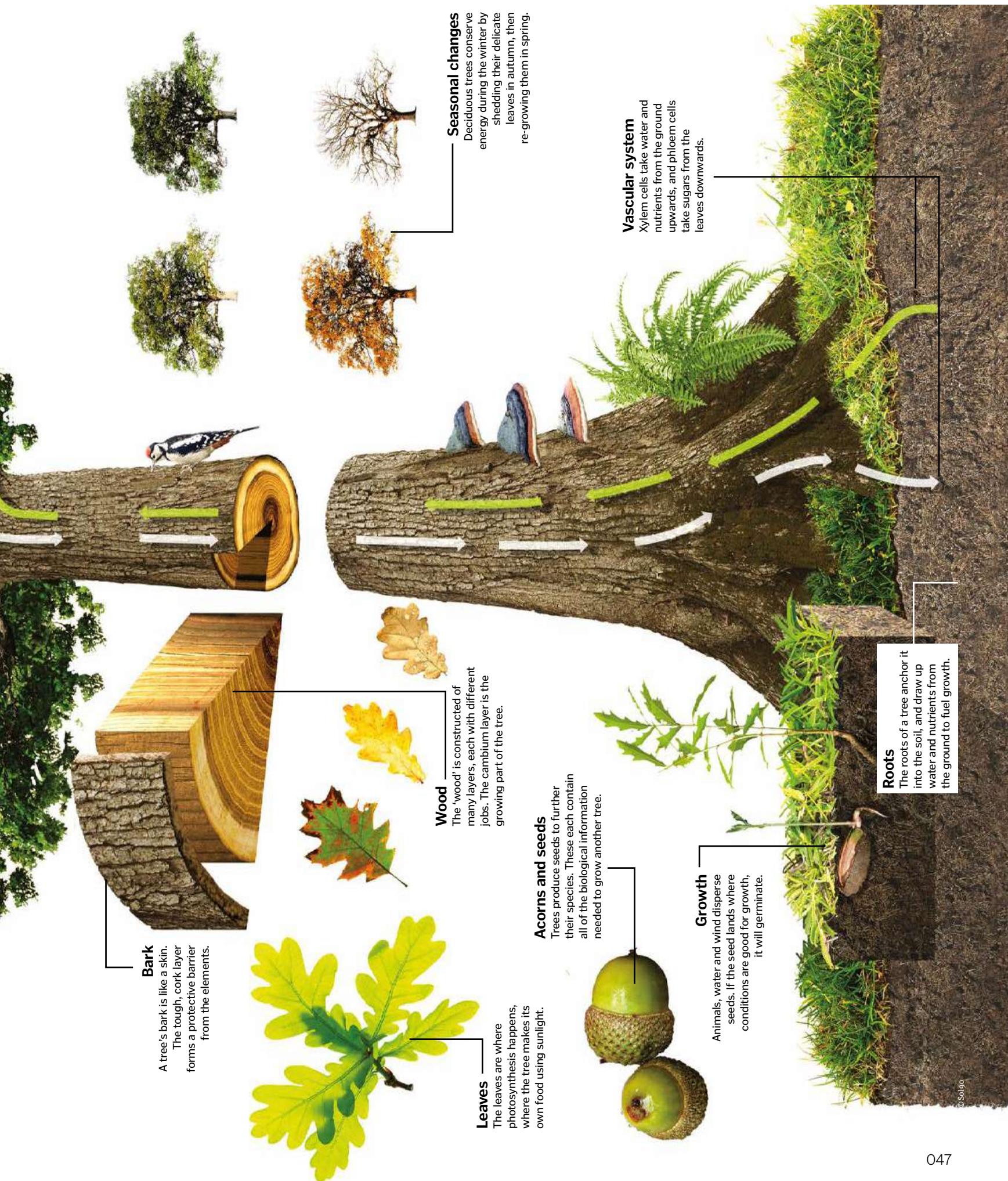
When you look at a tiny acorn on the forest floor, it's difficult to imagine just how much potential that little seed contains. If it germinates, after around 50 years it will have grown into a towering oak tree, with the capacity to outlast generations of humans. And that's just one tiny acorn. Scientists have estimated that there are around 3 trillion trees on our planet, belonging to around 100,000 different species. Each of these trees contributes to regulating our climate and producing air for us to breathe, as well as many more important roles that may surprise you.



## Flowers

Trees flower for the same reason as other plants – to distribute pollen and reproduce.







# Woodland wildlife

Forests are home to more wildlife than any other landscape

**F**rom leaves to bark and everything in between, every inch of woodland is useful to one critter or another. Large populations of trees create many varied habitats, from pine forests to wet woodlands, each with different ecological properties and a unique wildlife population.

In summer, when a tree's leaves are in full bloom, the dense foliage of the woodland canopy absorbs the Sun's energy, providing shade and regulating the woodland's climate. Similarly, in the winter months, the dense network of leaves and branches are an effective barrier against pouring rain and howling wind, sheltering the animals within.

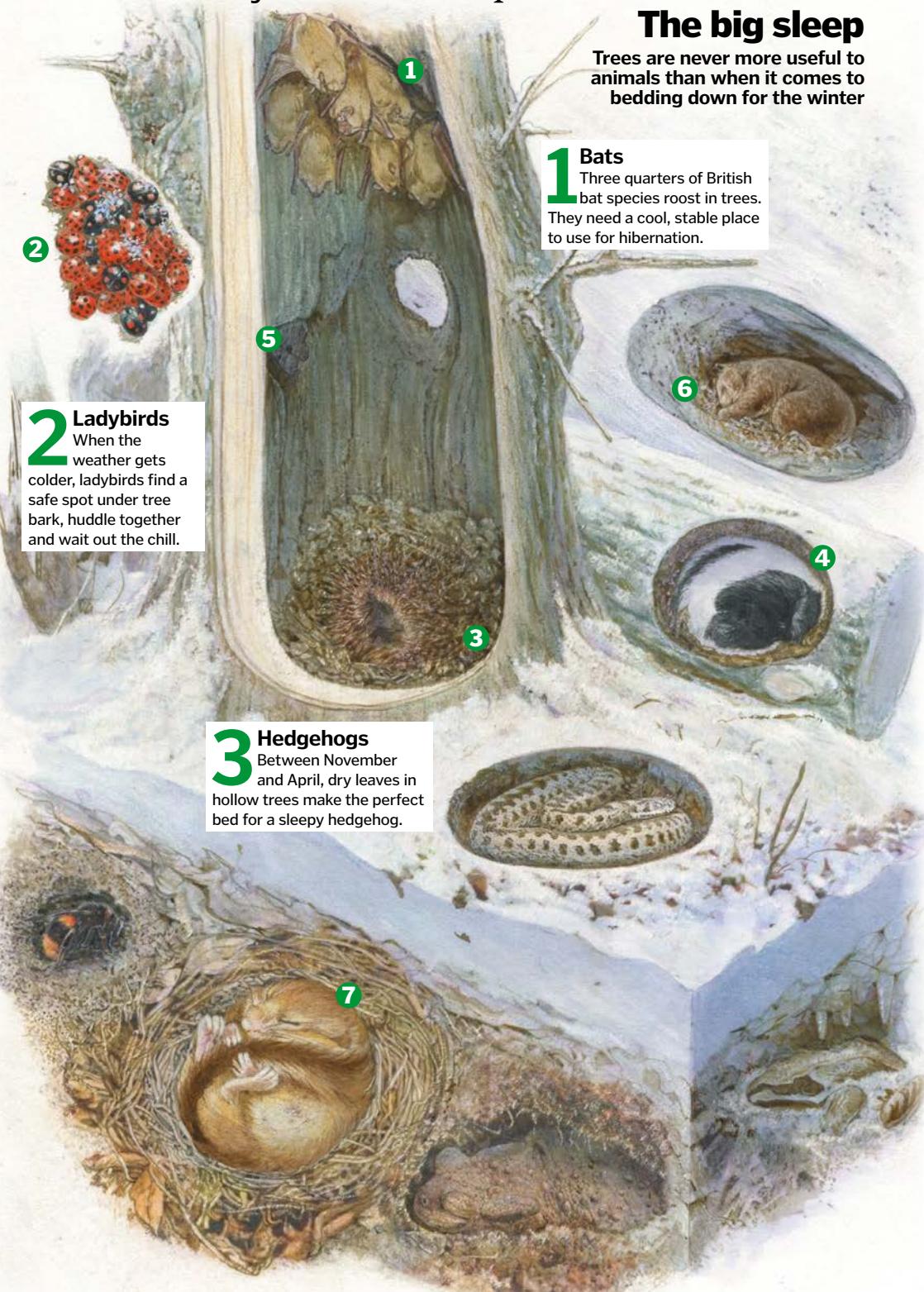
Green leaves, buds, fruit and bark provide food for many animals, such as squirrels, deer and birds. A tree's branches make handy perches for feasting upon, or a perfect vantage point to lie in wait for prey. Refuge is also found high up in the branches, safe from the clutches of forest-floor predators.

Lines of trees can also connect different ecosystems together, providing green corridors for animals to cross between different habitats, maintaining the flow of food and nutrients throughout the countryside.

The tree's structure itself provides plenty of nooks and crannies for wildlife to hide in. Birds build nests on branches or hollow out the bark, insects live on the underside of leaves, bats and dormice seek out tree cavities for refuge and burrowing critters weave throughout the roots. Even when a tree dies it's useful; leaf litter creates a rich mix of nutrients on the forest floor for scavengers, and dead wood can support countless plants, insects and fungal species.



Tawny owls make their homes in hollows of trees, sheltering from the elements.



**4 Badgers**  
Badgers live in tunnel networks known as setts. Tree roots make these underground dens more stable.

**5 Moths**  
Depending on the time of year, moths and caterpillars can use branches for hibernating in large groups.

**6 Bears**  
These great beasts will collect leaves, branches and brushes of trees to create a warm bed to curl up in.

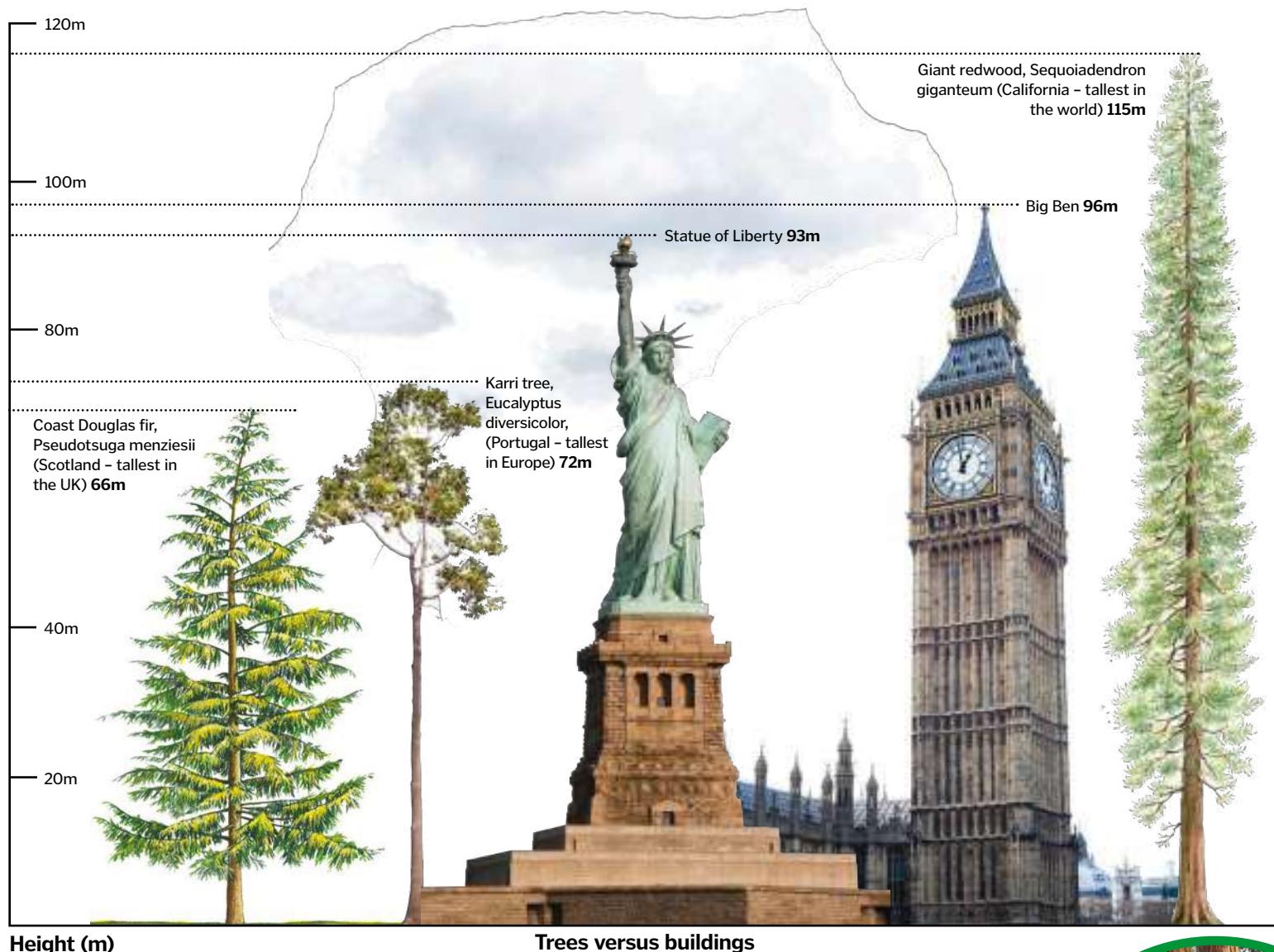
**7 Dormice**  
Found living in deciduous woodland, dormice make cosy nests to keep out of the winter chill.

## The big sleep

Trees are never more useful to animals than when it comes to bedding down for the winter

**1 Bats**  
Three quarters of British bat species roost in trees. They need a cool, stable place to use for hibernation.

## The world's tallest trees



# The importance of trees

The forest does far more for us humans than provide beautiful walks and firewood

**T**rees are the lungs of our planet. As a key part of the carbon cycle, when trees photosynthesise to make their own food, they take in carbon dioxide and convert it to release oxygen, storing the rest of the carbon that gets decomposed into the soil when the tree dies. When a whole forest does this, the intake of CO<sub>2</sub> is huge. With rising CO<sub>2</sub> levels in our atmosphere being an important factor in

climate change, the work of trees becomes all the more prominent. It's estimated that our planet's trees absorb up to 40 per cent of the carbon dioxide created by humans each year.

When the trees are cut down, this carbon storage is removed, but so is the tree's ability to stabilise the earth and take up water. Deforestation creates a landscape where water flows uninterrupted, taking valuable, nutrient-

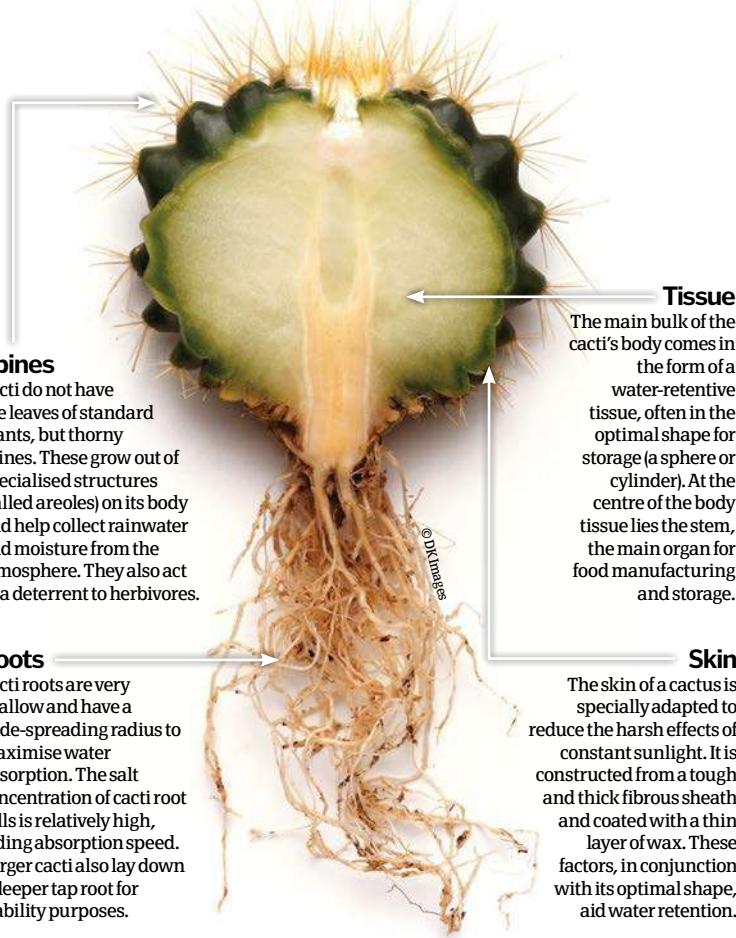
laden surface soil with it. This leaves land barren and infertile – a disaster for agriculture and those who depend on farming for their livelihood. Flash floods wreak havoc and threaten human life, and have been directly linked to the removal of trees across the world. Downstream, the soil that has been removed by floods is deposited as the flow peters out, and can clog up dams and create further issues.





# How do cacti live?

Take a closer look at the materials and mechanisms cacti use to survive in the world's harshest environments



## Spines

Cacti do not have the leaves of standard plants, but thorny spines. These grow out of specialised structures (called areoles) on its body and help collect rainwater and moisture from the atmosphere. They also act as a deterrent to herbivores.

## Roots

Cacti roots are very shallow and have a wide-spreading radius to maximise water absorption. The salt concentration of cacti root cells is relatively high, aiding absorption speed. Larger cacti also lay down a deeper tap root for stability purposes.

**Tissue**  
The main bulk of the cacti's body comes in the form of a water-retentive tissue, often in the optimal shape for storage (a sphere or cylinder). At the centre of the body tissue lies the stem, the main organ for food manufacturing and storage.

**Skin**  
The skin of a cactus is specially adapted to reduce the harsh effects of constant sunlight. It is constructed from a tough and thick fibrous sheath and coated with a thin layer of wax. These factors, in conjunction with its optimal shape, aid water retention.

**C**acti are hardy, flowering plants in the Caryophyllales order that have evolved to survive in some of the Earth's driest and most barren landscapes. This unceasing survival is achieved through the specialised tailoring of two main principles: form and function.

First, all cacti have developed optimal forms for retention of internal water supplies (spheres and cylinders), combining the highest possible volume for storage with the lowest possible surface area for loss. This allows cacti to store vast quantities of water for elongated periods – for example, the species *Carnegiea gigantea* can absorb 3,000 litres in a mere ten days. This ability directly correlates to the typical weather patterns of Earth's barren, dry environments, where cacti are predominantly found, with little water being deposited for months on end, only for a short

monsoon to follow in the rainy season. This optimal structural form also grants much-needed shadow for lower areas of the plant, shielding them from the harsh sunlight.

Second, cacti have evolved unique mechanisms and adapted traditional plant functions to grow and thrive. Foremost among these changes are the cacti's spines, elongated spiky structures that grow out from its central body through areoles (cushion-like nodes). These act as a replacement for leaves, which would quickly die if exposed to high levels of sunlight and high temperatures. The spines have a membranous structure and can absorb moisture directly from the atmosphere (especially important in foggy conditions) and also from deposited rainwater, capturing and absorbing droplets throughout the body's spiny matrix. In

addition, due to the lack of leaves, cacti have evolved so as to undertake photosynthesis directly within their large, woody stems, generating energy and processing stored water safely away from the intense sunlight.

Finally, cacti have modified their root structures to remain standing stable in the brittle, parched earth. Cacti roots are very shallow compared with other succulents and are spread out in a wide radius just below the Earth's crust. This, in partnership with an intense salt concentration, allows cacti to maximise their access to and absorbability speed of ground water, sucking it up before it evaporates or trickles down deeper into the Earth. For stability, many cacti also extend a main 'tap root' further into the Earth, in order to act as an anchor against high winds and interference from animals.

Spines gather moisture and also serve as a defence mechanism



## Flowers

All cacti have a floral tube that grows above a one-chamber ovary. Cacti flowers tend to be solitary, large and very colourful, and are pollinated by both wind power and animals. After pollination, the entire floral tube detaches from the body.



# How are plants cloned?

Find out how we make identical copies of plants and what benefits this offers

**T**he process of cloning plants has been used in agriculture for centuries, as communities split roots and took cuttings to efficiently create multiple plants.

Taking a cutting from near the top of a plant, placing it in moist soil and covering it will enable a new offspring to grow with the same genetic code as the parent from which it was taken. This method of cloning is very easy to do and is common among casual gardeners and industrial farmers alike. However, in more recent years the cloning of plants has made its way into the laboratory.

Responsible for that shift is German physiologist Gottlieb Haberlandt who was the first to isolate a plant cell and then try to grow an exact replica of the parent. His attempt ultimately failed, but the experiment showed enough promise to convince others to follow in his footsteps. The likes of Hannig in 1904 and Kolte and Robbins in 1922 ran successful experiments in which they also cultured plant tissue to create new versions.

The main benefit of cloning flora is that growers are able to guarantee disease-free

plants by cultivating cells from strong and healthy ones, leading to higher and more reliable crop yields. By taking cuttings from proven strains, a farmer can be sure his next generation of crops is equally successful.

Back inside the lab, the development of cloning through cultivating plant tissue allows for many plant species to even be adapted and improved upon. However this genetic modification remains a controversial topic to

many people, as some experts argue we can't predict what the consequences of this human interference will be.

Plant cloning can be as basic as snipping off a stem from a begonia or as complex as growing a tomato plant in a solution of inorganic salts and yeast extract, but nevertheless the process by which you can create two plants out of one remains a triumph of natural science.

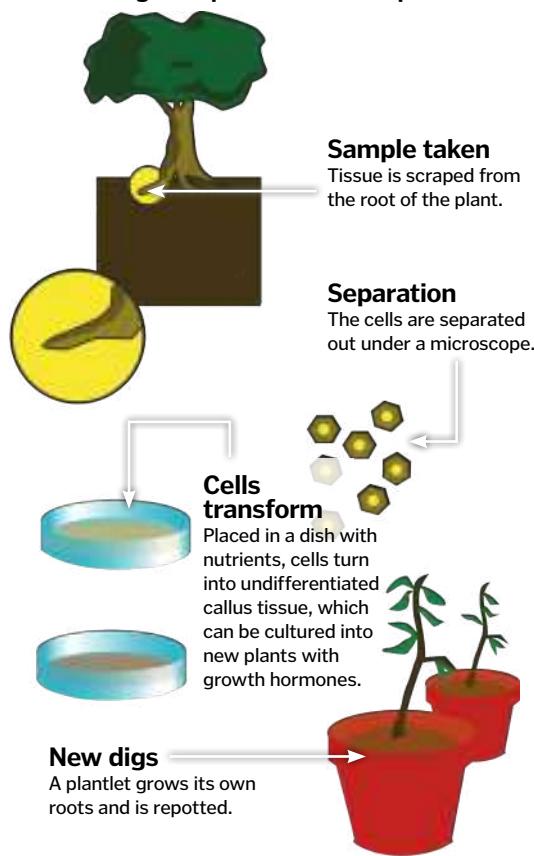
## What about animals?

Most of us are aware of Dolly the sheep, the first animal cloned from an adult cell, but artificial cloning dates back to the late-19th century. Hans Dreisch created two sea urchins by separating two urchin embryo cells from which two offspring grew, proving that DNA is not lost through separation. The next big development came in 1952 when a frog embryo was cloned by inserting the nucleus from a tadpole's embryo cell into an unfertilised frog egg cell. But the creation of Dolly in 1996, cloned using a mammary cell from an adult sheep, led to hopes that one day we might be cloned as well. There's still a while until a human can be replicated, but Dolly represented a huge leap forward in terms of cloning possibilities.



## Plant duplication guide

Discover how plants can be cloned in the lab through the process of cell separation





# EARTH'S LANDSCAPES

054  
**Extreme  
Earth**

- 054 Surviving extreme Earth**  
Explore our planet's wildest environments and make it out alive
- 064 Antarctica explored**  
Earth's coldest, windiest, highest and driest continent
- 068 Extreme oceans**  
Counting down the deepest, deadliest and stormiest environments on Earth





064  
**Antarctica  
explored**



068  
**Extreme  
oceans**



# SURVIVING EXTREME EARTH

The skills you need to journey into the wilderness and get out again alive



For many of us, the toughest conditions we'd ever have to face would probably be walking the dog in the bucketing rain. However, outside of the urban sprawl there are some places on Earth that aren't so hospitable to humans. While mankind has successfully populated large areas of the planet's land surface, there are still many places you wouldn't dare to venture unless you really enjoy a challenge or have just got horribly, horribly lost.

History is littered with people who have faced the biggest tests this planet has to offer, whether deliberately or accidentally, and lived to tell the tale, but many have fallen victim to frozen wastes or scorching plains. Even the best-prepared adventurers can come unstuck in the face of the amazing force of nature.

Over the next few pages we trek across deserts in search of water, dredge through jungles and scale icy mountains to uncover the dangers you're likely to come up against. Find out the equipment and skills needed to survive some of the most mind-boggling environments, where temperatures can plummet in hours, winds can reach breath-taking speeds and poisonous frogs can kill you where you stand.

We're not saying we will instantly turn you into the next Ranulph Fiennes, but it will hopefully give you a fighting chance should you find yourself in the depths of the Arctic Circle or in the middle of the Sahara.



# Beat the freeze

How to stay alive when you're freezing to death



Earth's north and south extremities are among the most inhospitable places on the planet. Even in the summer, temperatures are freezing and winds can reach up to 327 kilometres (200 miles) per hour, so it's no wonder the cold is the biggest killer here. If you're trekking across snowy wastes, better pack your thermals. Shrug on multiple layers of breathable fleeces and keep them dry. Any water will instantly freeze, as will any exposed flesh. Even nose hairs and eyelashes start icing over in minutes, so covering up is key.

Your body will respond quickly to the heat loss by tightening blood vessels near your skin. This is the reason we look paler when we're cold and why our fingers and toes become numb. Meanwhile, your muscles will start moving involuntarily, causing you to shiver. It can boost heat production by up to five times, but that uses up a lot of energy so you'll need to keep eating and drinking. Consume six to eight litres (10.6 to 14 pints) of water every day and around 6,000 calories, three times the typical recommended daily allowance. You can get this by melting butter into your food or munching on chocolate and bacon, so it's not all bad!

A word of warning, though: keep your eyes peeled. Hungry polar bears, particularly those with cubs to feed, can be very aggressive and they are masters of disguise. Flares and loud noises will often be enough to scare them away, but it's not a guarantee. You'll also need to watch your step as you go, as slipping through a crack in the ice can send you plummeting into the freezing cold ocean. It's generally safe to walk on white ice, but grey ice is only ten to 15 centimetres (four to six inches) thick and prone to cracking under pressure, while black ice is to be avoided at all costs since it will have only just formed. Tread very carefully, stay wrapped up and keep on the move if you want to have any hope of survival.

## Amazing animal

The arctic fox is an incredible little animal, well adapted to living in one of the harshest environments on Earth. Its furry feet and short ears are ideally suited to conserving heat in the unforgiving, freezing environment. Its coat is also adaptable; while its habitat is snowy its fur is brilliant white, hiding it from both prey and predators. However, as the ice melts, its coat turns brown or grey to hide among the rocks of the region. The arctic fox is an omnivore, feasting on rodents, fish and birds, but it will also eat vegetation when meat is difficult to find.



The snowy wastes of the polar regions are difficult to navigate



Polar bears are the Arctic's deadliest hunters



There is peril at every step as one wrong move can plunge you into icy waters



Little grows in this area so finding food is tough

## Life-saving kit

A rundown of what to wear to stay warm

### Hat

A hat with ear flaps that covers the head and neck is vital. A strap to secure it on the head will be useful in high winds.



### Goggles

The best goggles have a photochromic lens to help ward off glare from the ice and make sure you see cracks and holes.

### Thermal shirt

Your base layer should be a thin, thermal insulating top that wicks any sweat away from your body.



### Balaclava

You'll need to cover up as much as possible, so a woollen balaclava will keep the most heat in.

### Jacket

Your jacket will need to be both wind and waterproof to keep you dry and warm. Wrist holes in the cuffs keep it secured.



### Mittens

Although gloves offer more dexterity with actions, mittens are better as they keep your fingers together and much warmer.

### Boots

Warmth is vital – literally – so fleece-packed boots are good. Straps are better than laces but don't fasten them so tight it cuts off the blood supply.



### Trousers

Waterproof and windproof trousers are a must. Make sure they are also breathable, however, as you don't want your legs to become sweaty and lose valuable fluid.



## Ice fishing

Make a hole in the ice with an auger – a kind of drill that bores large holes. The ice you bore on should be light grey and about 15 centimetres (six inches) deep. Produce a hole approximately 0.5 metres (1.5 feet) in diameter. Set up your chair one metre (three feet) away from the hole and hold your rod over the top of it, with the line dangling in the water. The rod should only be about a metre (three feet) long and made of a sturdy material. Drop the baited line down around two metres (seven feet) and wait for a bite. Reel it in and keep it chilled before cooking!



This simple tool can find you a life-saving source of food

**AVERAGE DEPTH OF ICE IN ANTARCTICA – 2,126 METRES [6,975 FEET] EQUIVALENT TO 6.5 EIFFEL TOWERS**

**70%**  
ANTARCTICA'S ICE ACCOUNTS FOR 70 PER CENT OF THE WORLD'S FRESH WATER

4 MILLION PERMANENT INHABITANTS IN THE ARCTIC, NONE IN ANTARCTICA

**IF ALL THE ICE IN ANTARCTICA MELTED, THE SEA WOULD RISE 58M [190FT]. THE STATUE OF LIBERTY IS 93M [305FT] TALL**

## Survive the night

Build an igloo for protection



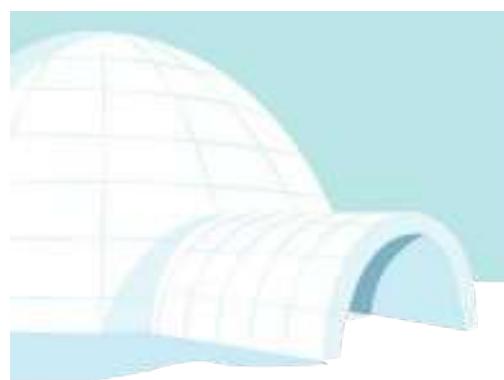
### Find your spot

The first trick to making your igloo is to build it on the side of a slope. This will mean less building for you to do. Dig a trench in the snow around 0.6m (2ft) deep. Get in and slice out blocks of packed ice from either side of the trench to ensure they are nice and uniform.



### Dig yourself in

Dig another trench into the side of the hill. It should be about 0.5 metres (1.6 feet) wide. This is the entrance trench. Leave a gap and dig another hole, but don't make it as deep as the entrance trench. This is your sleeping chamber, so make sure you fit in it!



### Construct the walls

Stack the ice blocks in a circle around the sleeping trench, leaving a gap around the entrance trench. Over the entrance trench, stack the blocks in a semicircle. Make the entrance tunnel as small as possible to minimise heat loss. Rub water over the blocks to fuse them together.



# Get out alive

Uncovering the dangers that lurk beneath the canopy of trees

 Few places on Earth house quite as many things that can kill you in so many ways as the jungle. From snakes to poisonous frogs, berries to rivers, anyone walking through the jungle needs to have their wits about them at all times.

The most obvious threat will come from big animals like tigers and jaguars that inhabit the jungles of India and the rainforests of South America respectively. Your best bet for evading these huge predators is to stand still and hope you weren't seen, or run and hide. If you are spotted, make yourself as big as possible and shout loudly as this will surprise and intimidate them.

Don't be fooled into thinking the smaller critters pose less of a threat, though. Many can

be deadlier than the big cats. The golden poison dart frog is particularly lethal to humans, as it has enough poison to kill ten adults. The poison is held in their skin, so eating or even touching one could have disastrous consequences. Add in the dangers of snakes, mosquitos, piranhas, crocodiles and bears, the jungle is not a place for the faint of heart. Take plenty of DEET-based insect repellent and make lots of noise as you travel so as to ward off creatures that would attack you out of fear or surprise.

While on your travels, be on the lookout for your next meal. On the menu will be fruit, plants, insects and fish, but you'll need a book to help weed out the edible from the poisonous. Avoid anything that's brightly coloured, because this is often an evolved defence

mechanism to warn against eating that particular plant.

But while it's possible to survive for about 60 days without food in warm conditions, you'll last less than 72 hours without water. Always ensure you have a filtration device or water purification tablets to make the water safe, or catch rain before it has hit the ground to prevent catching diseases like cholera.

Although there are a multitude of things that can kill you in the jungle, being clued up on what you can and can't eat and how to avoid predator attacks will help enormously. If you're lost and ready to scream "Get me out of here!" then following water will take you out of the jungle to the end of the waterway. Ant and Dec almost certainly won't be there to meet you.



Tigers in the jungles of India are deadly predators

# 10



THE NUMBER OF ADULTS A GOLDEN POISON FROG COULD KILL IN ONE GO



## Amazing animal

Bonobo monkeys are found in the jungles of the DR Congo and are one of our closest relatives. They share over 98 per cent of our DNA and have an astonishing ability to mimic human behaviour, including using tools and solving problems.

They have adapted superbly to life in the jungle, surviving on a varied diet of fruit, plant life, small rodents, insects, and even soil. This flexibility means they will never go hungry.

They are extremely social animals, living together in groups of up to 100. The females move from group to group to prevent inbreeding and the males stay in their social groups for life.



## Avoid man-eating predators

Three steps to remaining undetected in the jungle

### Cover your tracks

Predators like big cats are excellent trackers and they'll be keen to find you, especially if it's dinnertime. Walking in water will stop physical evidence of your movements, giving you a better chance of going undetected.



### Camouflage

Hide yourself as you walk through the jungle using camouflage. If you don't have a specific outfit, coat yourself with mud and attaching leaves and foliage to your body will make you less likely to be spotted.



### Cover your scent

Jackets lined with charcoal are excellent for preventing your natural odours from escaping into the environment. Otherwise, cover yourself in things like mud and strong smelling plants to mask your scent.



## Jungle protection

The clothes and kit to keep you hidden, cool and safe

### Sunglasses

The sunlight can be incredibly strong so you'll need some sunglasses with UV filters.



### Hat

A large brimmed hat will protect you from bugs falling from the trees and keep you relatively hidden from animals above you.

### Long sleeve shirt

A light, breathable fabric will keep you cool, but make it baggy so mosquitos can't get to your skin.



### Backpack

You'll need your hands free so a backpack is crucial. It needs to be waterproof, blend in with the environment and be comfortable.

### Bug spray

Mosquitos carry a huge array of diseases, not least malaria, so 100 per cent DEET spray is vital.



### Poncho

Sudden downpours are features of jungle and rainforest life, so a lightweight, quick-drying poncho is useful.

### LifeStraw

This device really could save your life. The filter inside the straw wipes out 99.99 per cent of bacteria in dirty water.



### Machete

The jungle is a tough landscape to negotiate, so a large knife or machete will help you work your way through the thick and difficult undergrowth.

### Trousers

Length is key here. You can't let your ankles get exposed because that's where mosquitos especially love to bite.



### Boots

Your shoes don't want to be too thick and heavy because they'll wear you down. Sturdy trainers or Wellington boots will surprisingly be enough.

## The edibility test

If you aren't a trained botanist, you might struggle to identify which plants are safe to eat. That's where the universal edibility test comes into play. Eat nothing and drink only water for eight hours before the test.

Your first task is to split up the plant you are testing into its individual components, such as the stem, root, leaf, flower and bud. Crush each part of the plant and, one-by-one, rub them on your skin to see if you have a bad reaction to it. If your skin blisters or forms a rash, it's unlikely to be good to eat.

If it's good, the next stage is to boil the plant, if possible. Hold the plant on your lip for a few minutes, removing instantly if it begins to burn. Finally, if the plant has passed the test so far, place it on your tongue. Again, if it begins to feel painful or look bad, spit it out and wash your mouth thoroughly. Remember though, tasting bad isn't the same as being poisonous!

Chew it for around 15 minutes and, if all still feels good, swallow it. Don't eat anything else for eight hours and see if you have any bad reaction to what you've eaten. If you're good, you've found a potentially life-saving food source!





# Escape scorching heat

How to survive the extreme temperatures of the desert

While the polar regions are always bitterly cold no matter what time of day it is, one of the major challenges in surviving the desert is dealing with the ridiculous changes in temperature. In the midday Sun, the mercury can reach as high as 50 degrees Celsius (122 degrees Fahrenheit) in the Sahara, but drop to below freezing by night. Your best bet is to wear a loose-fitting robe. This will let air circulate around the body and you won't get nearly as hot and sticky. At night, when the temperature plummets, you can wrap it around you for warmth.

It is vital that you protect your head. If you think a touch of sunburn from staying by the pool on holiday is bad, that's nothing compared to the effects of walking all day in the parched desert. Even if it means burning another part of your body, wrap something around your head and neck so you don't succumb to sunstroke, which can lead to hallucinations and fainting.

Other dangers in the desert will mostly come from scorpions. They hide in the sand and

deliver a sting with their tail that can paralyse and eventually kill. Sturdy boots will protect you from these creepy crawlies, as well as make travelling over sand much easier. While they don't make great pets, scorpions do provide a crucial source of nutrition. Picking them up by the tail just behind the stinger is the safest method and it will give you vital protein for your journey. Just don't eat the tail.

In the desert, you'll need to adjust your body clock. Aim to shelter during the day and travel at night. This has the dual benefit of avoiding the scorching sun and keeping you active during the freezing night. It also means you can keep on the right track easily by following the stars, hopefully leading to civilisation.

Shelter can come in the form of large rocks or cliffs. Alternatively, you can dig a trench down into the cooler sand and use clothing or some other material you have available to form a canopy over the top, secured by rocks or sand. As long as it is at an angle and not touching you, you'll be protected from the Sun's glare.

## Desert dress

The essentials to surviving in the hottest places on Earth

### Headwear

If you don't have any headwear, you could suffer with heatstroke, so protect your face and neck.



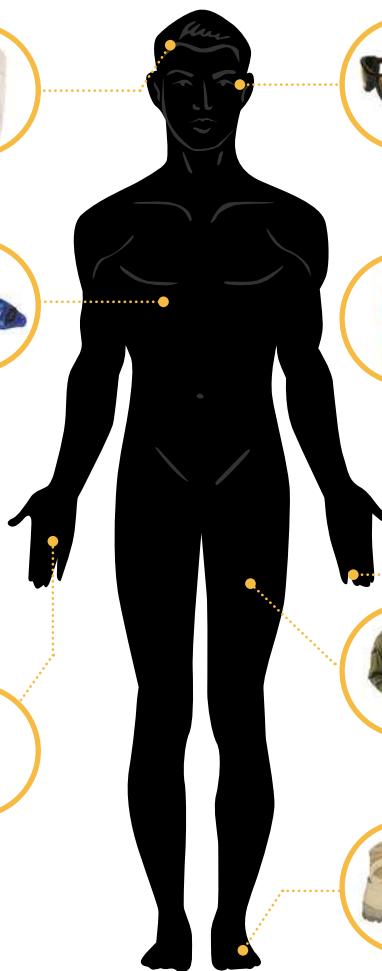
### Sleeping bag

A brightly coloured blanket will be useful as it would enable any search party to find you, will keep you protected in the day and warm at night.



### Sun cream

The baking temperatures will burn you in no time at all, so a high factor sun cream will provide at least some protection.



### Sunglasses

The desert throws up an awful lot of sand and glare, so sunglasses will be absolutely vital.



### Water bottle

This will be your greatest friend. Take small, regular sips and if you ever find a water source, fill it up as much as possible.



### Shirt

Your clothes will need to be as loose fitting as possible to minimise sweating and dehydration.



### Footwear

Even though you'll be desperate for sandals, trainers or walking boots will give you grip and necessary protection.



## Amazing animal

The camel is known as the ship of the desert, as this remarkable creature can travel without food or water for a long time.

Domesticated 3,000 years ago, camels have been an invaluable help to those who make their livelihood travelling the desert. They can carry 90kg (200lb) on their backs effortlessly and can travel up to 32km (20 mi) a day, with the added bonus of being able to last for at least a week without water and months without food.

Camels store fat in their hump to use as a food source and consume 145l (32gl) of water in one go, which they also store for later use. They have adapted wonderfully to the desert, developing a membrane across the eye and extra-long eyelashes to counteract sand storms. Their feet also are incredibly well protected with calluses and spread out for walking on sand.

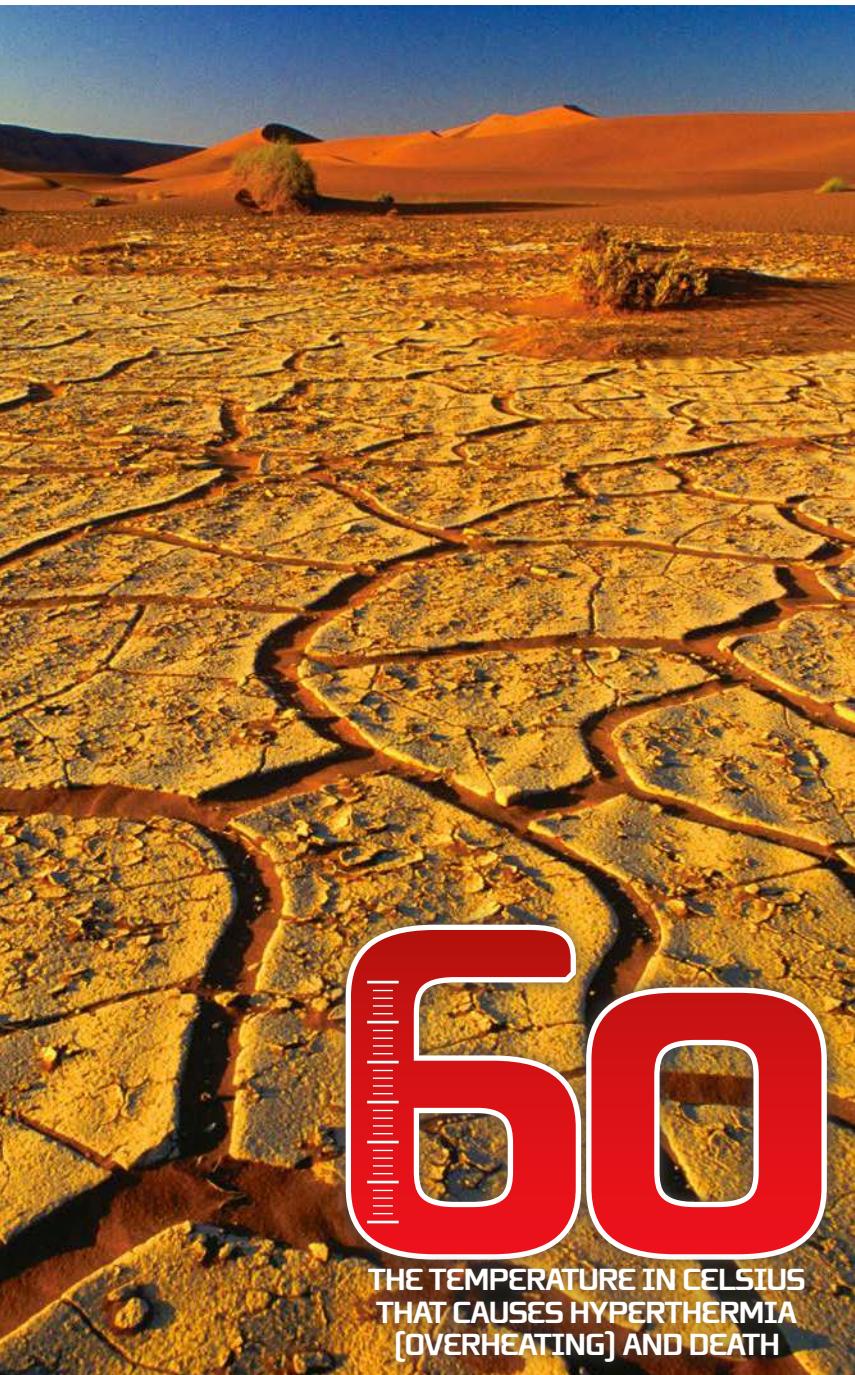


## Finding your way around

The desert is not only barren and featureless, but it is also a moving entity. Therefore, finding your way around is tough. The easiest way to find your way around is with a compass, but if that isn't available, travel at night and use Polaris, the North Star, as your makeshift compass.

Even though they are always shifting, sand dunes can also provide useful navigation hints. They always build up at 90 degrees to the direction of the wind, as the wind pushes sand upward to form them, so even when there's no wind, if you know the wind is northerly, the dunes will go east to west and you can use that information to navigate.

If you are lucky enough to have any landmarks, try and make a straight path between them so you know you are going in a straight line.



The plunging temperatures can leave you freezing cold without the right preparation



## Fight extreme thirst

Locate the desert's most precious resource



### Follow the wildlife

There are a number of birds and land animals that live in the desert and they all need water. Try and follow them wherever possible and hopefully they should lead you to a water source.



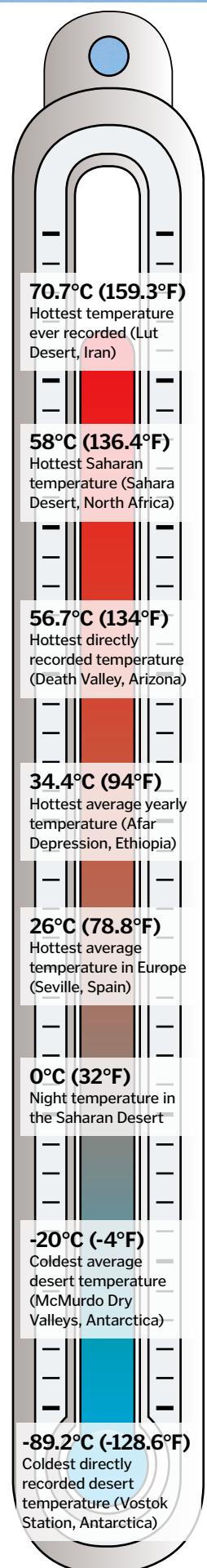
### Shady cliffs

In your quest for precious shade, you might also be lucky enough to find water. Dips and ridges that face north could be housing puddles and pools in their shaded, cooler spots.



### Grass is always greener

Plant life and vegetation means there is water around somewhere. Head down into valleys where there is plenty of greenery and even if there isn't a spring or pool around, you should be able to extract water from leaves or roots.





# Battle life-threatening altitude

How to cross the world's most treacherous terrain



Mountains are the ultimate test of survival. They're prone to rapid changes in weather and it's near impossible to predict. Even if the base is warm and sunny, by the time you reach the summit, low cloud can blind you, rain can make the terrain slippery and the cold can freeze you.

Good preparation is essential and you'll need a lot of kit. Pack a rucksack with a map, compass and a flashlight or headtorch, along with a brightly coloured emergency blanket, and dress in thermals and waterproof and windproof clothing. You'll also need to keep well hydrated. A lack of fluid at high altitude will result in dizziness, intense headaches and even frostbite. If you don't have any water to

hand, try to find a stream or melt some snow or ice to drink.

The altitude is a real issue for many mountaineers. As you climb higher, the air pressure reduces, meaning there is less oxygen for you to breathe. This lack of oxygen will cause your brain to reduce activity in all but the most important organs, making your limbs heavy and head dizzy. The most important thing to do is rest and re-oxygenate your body.

If you are trying to escape the mountain, the best way is to head downward, but this isn't always possible. Mountains have complicated structures and often there isn't an easy path down. If possible, put markers along your route to show where you have already been, to avoid

walking in circles. As well as being potentially confusing, mountains also hide dangerous crevices. Keep your eyes peeled for breaks in the snow or ice and if you are ever unsure, try to find rocks or stones to throw in front of you that could give away a hidden abyss.

If the visibility does become too poor, the safest thing might be to bed down. Find a spot out of the wind and protected from any snow or rainfall, like a cave or overhanging cliff. Even though it might sound strange, pack your surroundings with snow, because it does have insulating properties. Pile yourself with as many layers as possible and this should provide the warmth so you can make it through the night and try to find your way out in the light.

## Amazing animal

The mountain goat is amazingly adapted to life on the mountainside. Their hooves are curved and flexible to provide them more grip and traction on the treacherous slopes. Despite looking spindly and thin, their legs are actually very strong and they can leap surprisingly large distances.

They have two coats, a warm, woolly undercoat and a thinner but longer overcoat, which keeps the insulating undercoat dry. This system is how they can stand the cold temperatures long after bigger animals have given up and descended down the mountain in cold weather.

GoPros are a great way to record your adventure



## Mountain gear

What you need to brave the harsh, mountainous environment

### Beanie

A tight-fitting hat will keep lots of heat in as well as not being likely to fly away!



### Mittens

Although it would be useful to have fingers available for gripping ledges, it's more important to have your fingers warming each other.



### Rope

A strong and sturdy rope will help you protect yourself while asleep and also aid you in climbing or negotiating dangerous paths.



### Trousers

You need to keep dry and have items accessible, so a pair of waterproof trousers with zipped pockets will be the most useful.



## Keep a record

It's always handy to have a visual record of your travel by using a video recorder like the Hero3+ from GoPro. This camcorder is incredibly robust, lightweight and waterproof. It can also be attached onto helmets or bags, leaving your hands free to scale the treacherous mountainside.

Using a GoPro camera will also be useful as, once you get off the mountain to safety, you and a professional will be able to look over the footage, determine what went wrong and see how you could avoid getting stuck in the same situation again. The Hero3+ is available at [www.camerasjungle.co.uk](http://www.camerasjungle.co.uk).

### Headlight

A powerful headlight will be essential for finding your way around in darkness without wasting a hand on a torch.



### Coat

Lightweight is key here because you don't want to be weighed down. Bright colours will also make you visible to rescuers.



### T-shirt

A tight-fitting T-shirt made of breathable material will keep body heat in without making you sweat.



### Flare

If you can send up a flare, do so at night. Not only will it attract the attention of rescuers, it might ward off predators.



### Boots

A high-legged boot will keep the worst of the snow and water out, while the sole will need to be rugged and have tons of grip.



## Keep the fire burning

How to warm up on the mountainside

### Find some wood

You'll want a variety of wood, from small sticks and twigs, all the way up to sizeable branches and logs. The smaller bits will light much more quickly while the bigger pieces will burn longer, hotter and form the bulk of the blaze.



### Build your base

Dig a small pit in the ground. Surround it with stones so the fire doesn't get out of control. Place the smallest bits of wood at the bottom of the pile, but leave some gaps to keep the fire supplied with the oxygen it needs to burn.



### Light the fire

Place the larger branches and logs at an upwards angle, allowing the air to circulate and ensuring all the wood is getting burned evenly. Make sure everything is connected so fire can transfer from one piece of wood to another.



The weather can turn in an instant, so make sure you're prepared for anything

**7500**

HEIGHT IN METRES AT WHICH NEARLY A THIRD OF CLIMBERS GET HALLUCINATIONS



Crevices and cracks await the unwary traveller



# Antarctica explored



## What's large, hostile and used to trial missions to Mars? Antarctica – the world's coolest continent

**A**ntarctica is the world's last great wilderness and Earth's coldest, windiest, highest and driest continent. Around 98% of the land area lies buried beneath kilometres of snow and ice, yet Antarctica is – paradoxically – a desert. In fact, it is so inhospitable that no one lives there permanently, despite it being 25% bigger than Europe. This frozen continent remained unexplored until the 19th century. Unveiling its mysteries claimed many lives.

Antarctica is definitely worth a visit from your armchair, however, because it may also be Earth's quirkiest and most remarkable continent. Among its marvels is a river that flows inland, Mars-like valleys where NASA scientists test equipment for space missions, and perpetually dark lakes where bacteria may have survived unchanged since Antarctica had lush forests like the

Brazilian rainforest. Living in and around the Southern Ocean that encircles Antarctica are fish with antifreeze in their blood, the world's biggest animal, and a giant penguin that survives nine weeks without eating during the harsh winter.

Antarctica is the chilliest place on Earth. At the Russian Vostok scientific research station in the cold, high continental interior, it can get cold enough for diesel fuel to freeze into icicles – even in summer. Vostok is the site of the coldest temperature ever recorded on Earth – an amazing -89.2°C (-128.6°F). The temperature in most freezers is only about -18°C (-0.4°F).

The continent is also Earth's windiest. Antarctica's ice cools the overlying air, which makes it sink. This cold, heavy air accelerates downhill, creating wind gusts of over 200 kilometres (124 miles) an hour. The

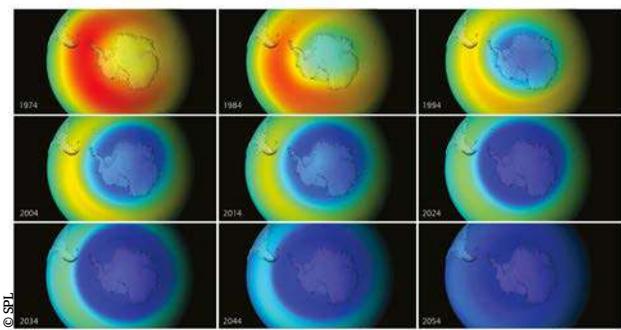
sinking air at Vostok is so dry that some scientific researchers pack hospital IV (intravenous) drip bags to stop becoming dangerously dehydrated. Few clouds can form in the dry air, and most moisture falls as snow or ice crystals. Any snow that falls accumulates because it can't melt in the extreme cold.

If the climate wasn't harsh enough, Antarctica never sees daylight for part of the winter because the sun barely rises over the horizon. Even in summer, the Sun is feeble and low in the sky. The extreme cold partly explains why two huge ice sheets cloak Antarctica. The white ice cools it further by reflecting away about 80% of incoming sunlight. Together, these ice sheets contain around 70% of the world's fresh water. If they melted, global sea levels would rise by 70m (230ft) and swamp many of the world's major cities.

Antarctic mountains, pack ice and ice floes



© Jason Auch



# A world without ozone?

## A 'hole' still exists over Antarctica

It's 2065, and skin cancer rates are soaring. Step outside in some cities and you'd be sunburned in ten minutes. That's the vision of NASA chemists, who predicted Earth's future if 193 countries hadn't agreed to stop producing CFCs in 1987. CFCs are man-made, chlorine-containing chemicals that destroy the Earth's ozone layer high in the atmosphere, which protects us from the sun's UV radiation. A 'hole' in this layer was discovered over Antarctica in the Eighties and persists today, because CFCs linger in the atmosphere for 50 to 100 years. The hole formed because the freezing winters allow unusual cold clouds to form. Chemical reactions on the cloud surface transform the chlorine in CFCs into an ozone-destroying form.

### Size comparison

Antarctica is 14 million km<sup>2</sup>

(5.4 million mi<sup>2</sup>) in area.

Compare that with

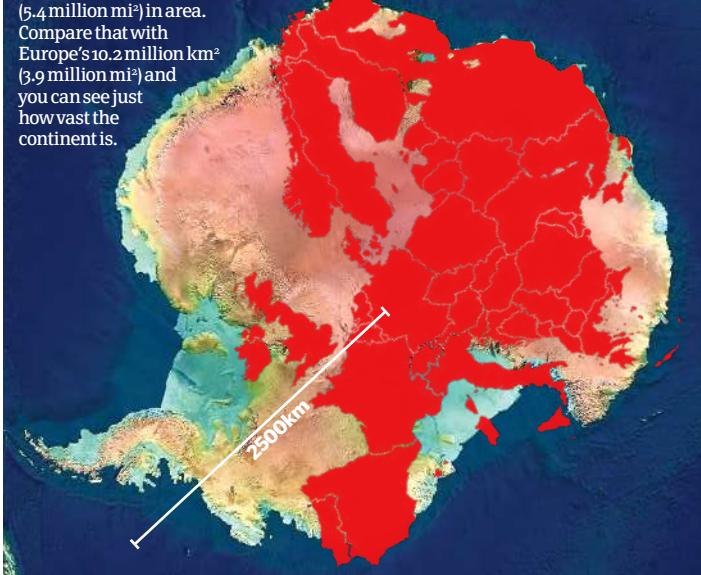
Europe's 10.2 million km<sup>2</sup>

(3.9 million mi<sup>2</sup>) and

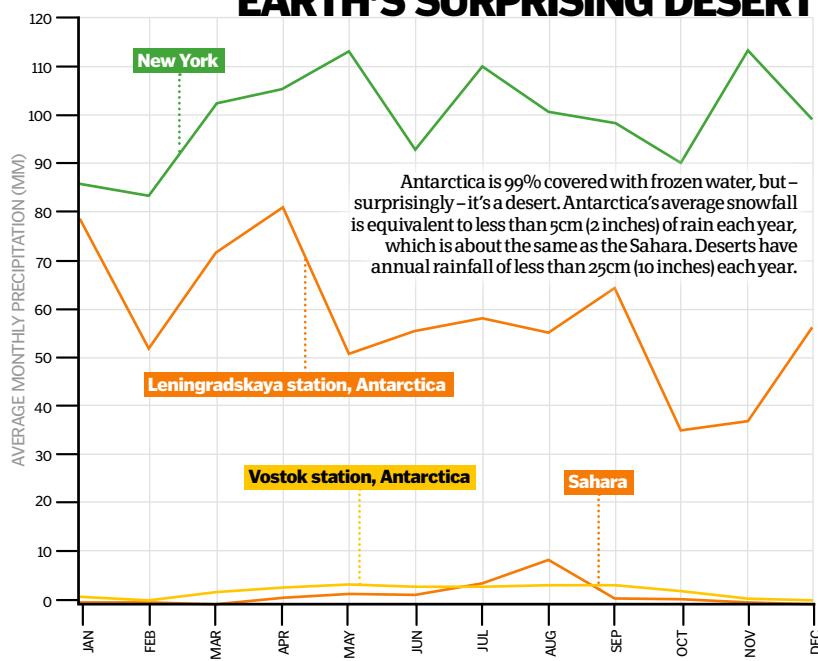
you can see just

how vast the

continent is.



## EARTH'S SURPRISING DESERT



sheets of ice attached to the land called 'ice shelves'. The biggest is the Ross Ice Shelf, which covers approximately the area of France and is several hundred metres thick.

One of the world's biggest mountain ranges separates the two ice sheets. The Transantarctic Mountains are more than two kilometres (1.2 miles) high and 3,300 kilometres (2,051 miles) long – more than three times the length of the European Alps. The mountains were formed around 55 million years ago during a period of volcanic and geological activity. Volcanoes like Mount Erebus are still active today.

Antarctica's main ice-free area is the McMurdo Dry Valleys, a region with conditions like Mars through which runs the continent's longest, largest river. The Onyx River carries summer meltwater 40 kilometres (25 miles) inland from coastal glaciers to feed Lake Vanda, which is saltier at its bottom than the Dead Sea. The salinity of Dry Valley lakes like Lake Vanda allows their deep water to stay liquid at temperatures that are below the freezing point of fresh water. Other strange Antarctic lakes include Lake Untersee in the East Antarctic interior, which has

"We're afraid if your name's not on the list, we can't let you in..."



The East Antarctic ice sheet is the largest on Earth, with ice more than three kilometres (two miles) thick in places. Under the ice sheet are some of the oldest rocks on Earth – at least 3,000 million years old. The West Antarctic ice sheet is smaller, and drained by huge rivers of ice or glaciers. These move slowly in Antarctica's interior, but accelerate to up to 100m (328ft) per year towards the coast. The fastest is Pine Island glacier, which can flow at more than three kilometres (two miles) per year. When these glaciers hit the sea, they form huge, floating





water with the alkalinity of extra-strength laundry detergent.

Despite the harsh conditions and the lack of soil, animals and plants survive on ice-free parts of Antarctica. In the windswept Dry Valleys, lichens, fungi and algae live in cracks in the rocks. Towards the coast, on islands and the peninsula, mosses are fed on by tiny insects, including microscopic worms, mites and midges. Some insects called springtails use their own natural antifreeze, so they can survive temperatures of less than  $-25^{\circ}\text{C}$  ( $-13^{\circ}\text{F}$ ). There are even two species of flowering plants to spot.

In contrast, the Southern Ocean surrounding Antarctica is among the richest oceans in the world. The annual growth and melting of sea ice dredges nutrients from the ocean depths, resulting in phytoplankton. A single litre of water can contain more than a million of these tiny plants. The phytoplankton are eaten by krill – tiny shrimp-like creatures that are the powerhouse of Antarctica's ecosystem and feed most of its predators, including seals, fish, whales and penguins. They form dense swarms, with more than 10,000 krill in each cubic metre of water. Some swarms extend for miles and can even be seen from space. Alarming recent studies show that krill stocks have fallen by 80% since the Seventies, probably due to global warming.

All of Antarctica's species are adapted to the extreme cold. Seals and whales have a thick layer of blubber for insulation and penguins have dense, waterproof plumage to protect them from salty, surface water at

# Antarctica's top sights

## Larsen Ice Shelf

A Luxembourg-sized area of the Larsen Ice Shelf collapsed in only 35 days in 2002. Scientists said it was the first time the shelf had collapsed in 12,000 years.

## Antarctic Peninsula

The Antarctic Peninsula is a mountain chain typically more than 2km (1.2mi) high that protrudes 1,334km (829mi) north towards South America. It's the warmest, wettest part of Antarctica.

## South Pole

The geographic South Pole is where Earth's longitude lines converge. The striped ceremonial Pole where pictures are taken is about 90m (295ft) away from the real Pole, which is on a moving glacier.

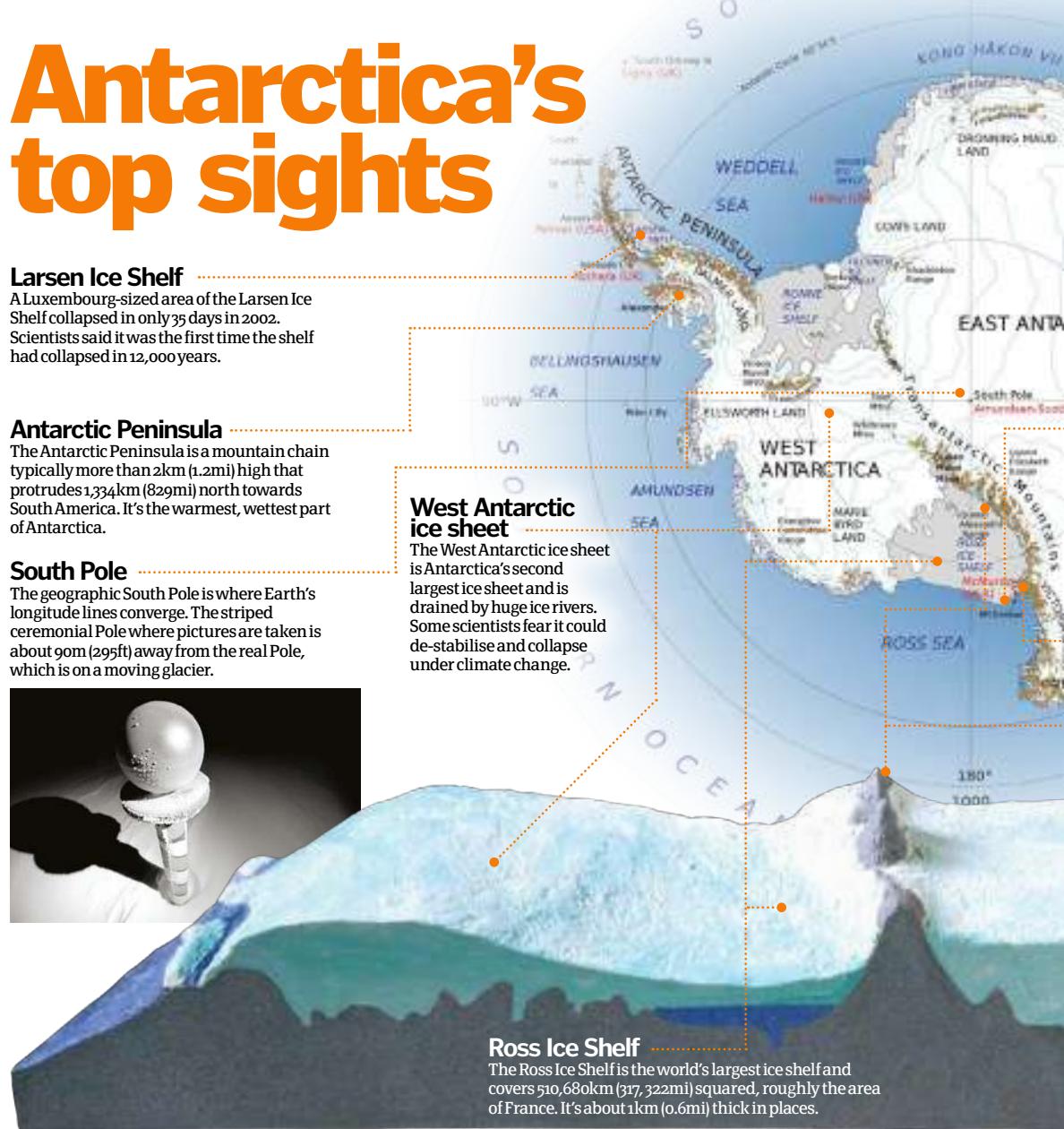


## West Antarctic ice sheet

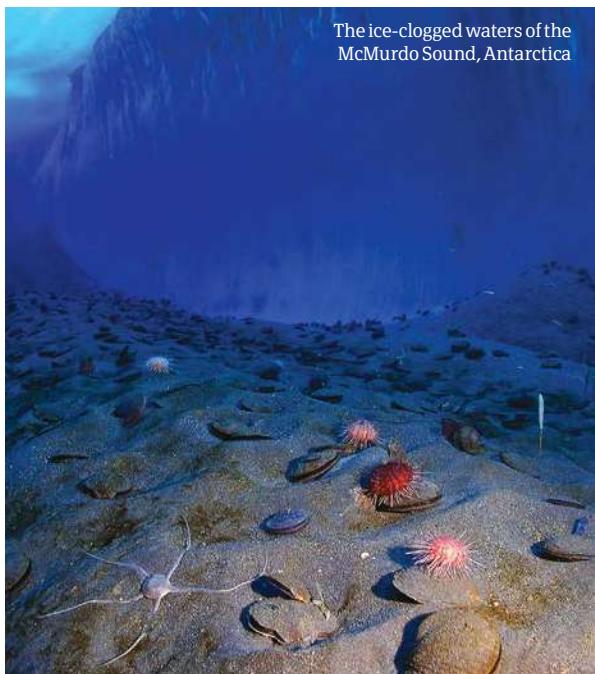
The West Antarctic ice sheet is Antarctica's second largest ice sheet and is drained by huge ice rivers. Some scientists fear it could de-stabilise and collapse under climate change.

## Ross Ice Shelf

The Ross Ice Shelf is the world's largest ice shelf and covers 510,680km (317,322mi) squared, roughly the area of France. It's about 1km (0.6mi) thick in places.



The ice-clogged waters of the McMurdo Sound, Antarctica



a frigid  $-1.8^{\circ}\text{C}$  ( $29^{\circ}\text{F}$ ). Some species of fish have antifreeze in their blood. Antarctic icefish have transparent blood and absorb oxygen through their skin.

The most common birds are penguins. Of the 17 species of Antarctic penguins, only two live on the continent itself. One is the world's largest penguin, the emperor penguin, which grows to 115cm (4ft) tall. Being large helps the penguin to keep warm. Emperor penguins breed on Antarctica's sea ice during the cold, dark winter, enduring blizzards and low temperatures. The male penguins keep their eggs warm by balancing them on their feet for up to nine weeks, while the female goes fishing at sea. During this fasting period, these super-dads huddle in groups of up to 5,000 penguins to keep warm, losing 45% of their body weight.

During the summer, around 4,400 scientists and support staff live on

Antarctica, carrying out experiments. Some are drilling to extract cylinders of ice more than three kilometres (two miles) long, to provide a record of the climate covering perhaps the last 740,000 years. The ice contains ancient air bubbles and compressed layers of snow. Scientists are also drilling into underground lakes like Lake Vostok, which may contain water and microbes isolated from the outside world for a million years.

Astrophysicists also benefit from Antarctica's clean, dry air. IceCube is an Antarctica-based experiment that tracks neutrinos, ghostly particles created by exploding stars. Another experiment is attempting to detect faint light from the Big Bang that created our universe. Scientists are also studying the feeding habits of Adélie penguins, using scales to check their weights on their favourite walking routes.

**DID YOU KNOW?** Antarctica's biggest purely terrestrial animal is a wingless midge, which grows to just 1.3cm (0.5 inches) long



Lake Vanda has the clearest ice in the world (as transparent as distilled water), and it's possible to see straight down for many metres



#### Mount Erebus

Mount Erebus is among Earth's largest active volcanoes. Heat escaping the volcano melts the snow above into caves. The steam released freezes instantly into chimneys up to 18m (60ft) high.

#### East Antarctic ice sheet

The East Antarctic ice sheet is Earth's largest. It is more than 3km (2mi) thick in places and mainly flat, vast, featureless polar desert swept by icy winds.

#### Dry Valleys

The McMurdo Dry Valleys are Antarctica's largest ice-free area and resemble Martian landscapes. They contain mummified seal remains, salty lakes and a river that flows inland in the summer.

#### Lake Vostok

Lake Vostok is the biggest of 145 lakes buried beneath Antarctica's ice. Discovered in 1996, it's the largest geographic feature discovered on Earth in the last 100 years.

#### Transantarctic Mountains

The Transantarctic Mountains are among the world's biggest mountain ranges and divide Antarctica in two. They are 3,300km (2,051mi) long, with treeless peaks over 3km (2mi) high.

## Lake Vostok – an alien world

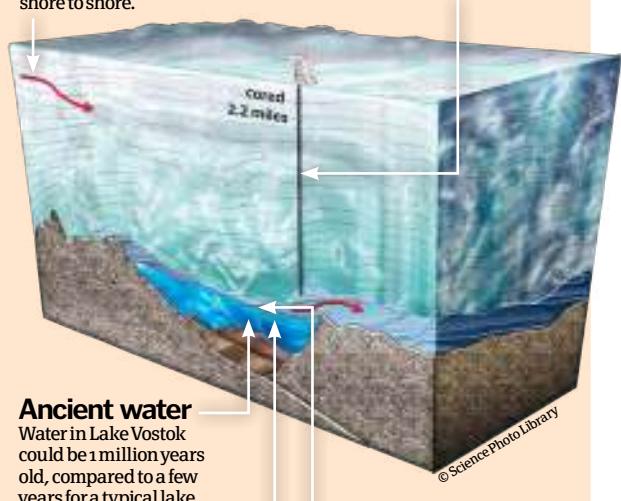
Discover the largest lake beneath Antarctica's surface

#### Ice flow

The mass of ice on top of the lake takes thousands of years to creep from shore to shore.

#### Life search

Russian researchers are drilling to the lake water through 4km (2.5mi) of ice to search for life.



#### Ancient water

Water in Lake Vostok could be 1 million years old, compared to a few years for a typical lake.

#### Sloping lake surface

The lake surface slopes downwards because the ice is about 400m (1,312ft) thicker at one end than the other.

An over-sea ice seismic survey in progress



## Early expeditions across Antarctica

By the late 19th century, Antarctica was Earth's last unexplored continent. The South Pole was the remotest place. The Pole was reached in December 1911 by Norwegian explorer Roald Amundsen who pioneered a new route. Amundsen's party raced the British expedition led by Robert Scott who arrived 33 days afterwards, having battled harsh weather and terrain. Scott's dispirited party died from starvation and exposure on the return journey. In 1914, Ernest Shackleton tried crossing Antarctica, but his ship 'Endurance' was crushed by winter ice. All his crew survived almost two years camping on the ice, until Shackleton led an epic 1,300 kilometres (808 miles) trip in a small boat to seek help. From 1928 onwards US explorer Richard Byrd led five expeditions to Antarctica, claiming vast territories for the USA. In November 1929, he flew over the South Pole. Today, the Pole is no longer uncharted territory – it even has its own post office!



**Ernest Shackleton**  
1914-1916



**Richard Byrd**  
1928-1930



**Roald Amundsen**  
1911 to 1912



**Robert Scott**  
1911-1912



# Extreme oceans

Counting down the deepest, deadliest, stormiest and downright most hostile environments on Earth



New South Wales, Australia  
Tasman Sea / South Pacific

# 1 Most shark-infested

Just like *Jaws*, only less cinematic trickery and more lose-a-leg scary

**W**hen it comes to shark attacks, there are three species that sit firmly at the top of the food chain: the great white shark, the tiger shark and the bull shark. This is one gnarly trio of hungry fish, who are all keen predators with heightened senses.

The most extreme place on Earth for shark attacks recently is New South Wales coast in Australia and over the last year the country has seen two fatalities, 18 injuries and 29 attacks. It's thought that changing ocean currents are bringing the sharks' prey closer to shore, luring in the ocean beasts alongside the fish.

However, before you march out with your torch and pitchfork to chase the sharks from the bays, it's worth bearing in mind that many more people are killed by the water that sharks swim in than by shark attacks themselves. Humans are naturally not a good diet choice for a shark – we are too bony with far too little blubber on us. Sharks need prey that is high in fat, such as seals.

Very often a great white shark will bite a human as a curious nip to find out what they are, rather than in an attempt to feast on them. That said, when you're swimming in an area with a known shark presence, the best advice is to get out of the water. Swim calmly and smoothly, as thrashing around will only draw the shark's attention, and don't ever wear jewellery or anything shiny that could make the shark think that you're a tasty fish covered in scales.

65,000 km

Length of the Mid-Ocean Ridge

The subterranean canyon off the coast of Nazaré creates incredibly tall waves, making it a popular surfing spot



# 2 Tallest waves

It's the stuff of every big-wave surfer's dreams: the 30-metre wave. Praia do Norte near the coastal village of Nazaré in Portugal is at one of the most westerly points of Europe, and bears the brunt of the sweeping Atlantic swells. Europe's largest underwater canyon, Nazaré Canyon, lies just

offshore, which is a 200-kilometre long ravine that works to combine the energy from waves that have travelled across the Atlantic, currents from the canyon, gusting winds and local tidal forces into colossal waves.

**Where:** Nazaré, Portugal  
**Ocean:** Atlantic Ocean

31 DAYS  
The longest-lasting hurricane

## WHERE ARE THEY?



# 3 Fastest growing

Plate tectonics can cause chaos through earthquakes, but they can also cause oceans to grow. The region offshore from Chile and Peru on the East Pacific Rise, where the Pacific plate is pulling away from the Nazca plate, is the site of the fastest seafloor spreading on Earth. This is where two plates pull away from each other, and magma bubbles up from the Earth's core to fill the gap. In this region, up to 16 centimetres of new seafloor is produced per year.

**Where:** East Pacific Rise  
**Ocean:** Pacific Ocean



# 4 Extreme storms

Where: Tropical Pacific  
Ocean: Pacific Ocean

Is there such a thing as the 'perfect storm'?

Fishermen who make their living out on the waves, battling everything the Pacific throws at them, will tell you that this is one of the cruellest oceans on Earth.

It's the tropical region that whips up this meteorological frenzy and creates the mother of all storms: hurricanes. Fed by very warm, moist air, these weather systems usually form between June and November, and need to reach 120 kilometres per hour or more to be classified as a hurricane, typhoon or cyclone. These three terms describe the same event and just depend on the origin of the storm. In the Atlantic and Northeast Pacific the storms are hurricanes; in the Northwest Pacific they're known as a typhoon; and in the South Pacific and Indian Ocean the weather system is termed a cyclone.

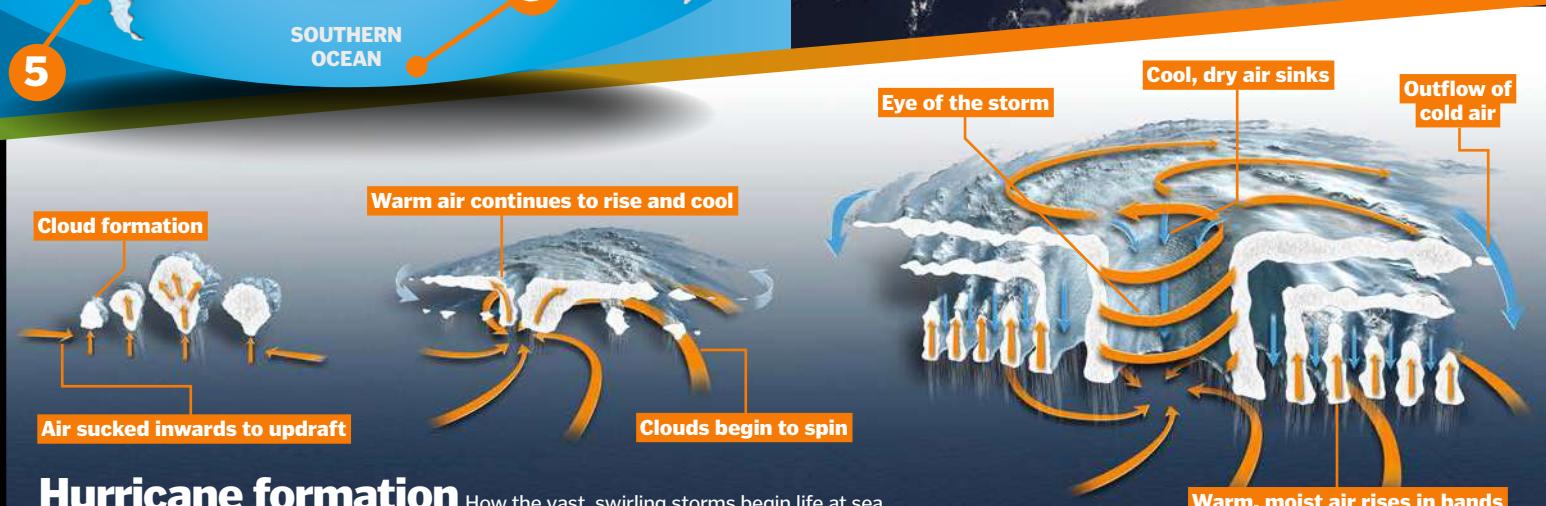
Hurricanes can travel huge distances across oceans, spinning anticlockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere, fed by the warm conditions of the tropics.

## WHERE ARE THEY?



1.3bn  
km<sup>3</sup>

Amount of water (approximate) in the oceans



## Hurricane formation

### 1 Cloud formation

Over warm, tropical waters, seawater begins to evaporate. As it rises, it cools to rapidly form clouds. Cooler air from the surrounding area rushes in to replace the warm air, which then warms up and rises again, causing updrafts.

### 2 Rotation begins

The warm air continues to rise, cool and suck in more air from the surroundings below, gaining energy. As the Earth rotates, the clouds start to spin too. A hurricane is formed once wind speeds reach 120km/h.

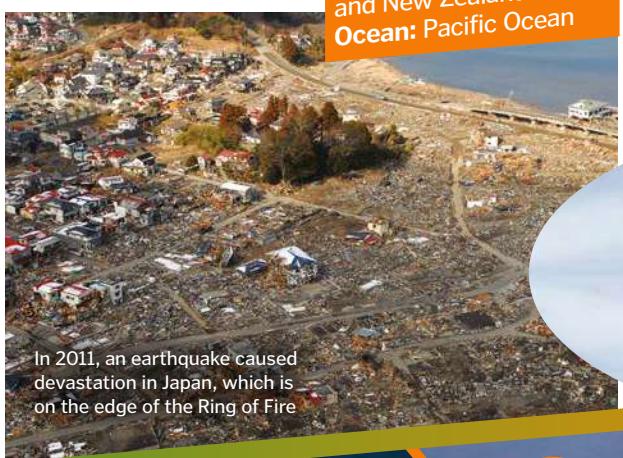
### 3 Mature storm

Warm, moist air continues to rise from the ocean and forms clouds in bands around the eye of the storm. Cool, dry air sinks through the eye and also flows out between the cloud bands at the edges of the storm.

## 5 Deadliest

### An entire ocean poised and ready for destruction

Beneath the Pacific Ocean lies a patchwork of molten terror known as the Ring Of Fire. Earth's crust is made up of tectonic plates that fit together like a jigsaw, floating over a layer of molten rock. At boundary zones, plates rub against each other, push against one another or pull away from one another, each with differing consequences. In the Pacific Ring Of Fire, the landmasses that surround the ocean are at the boundaries of these plates. Home to 90 per cent of earthquakes, the Ring Of Fire is a hotbed of tectonic activity.



In 2011, an earthquake caused devastation in Japan, which is on the edge of the Ring of Fire

**Where:** South America, North America, across the Bering Strait, Japan and New Zealand  
**Ocean:** Pacific Ocean

**Where:** Gulf of Mexico dead zone  
**Ocean:** Atlantic Ocean

## 6 Most polluted

The dead zone in the Gulf of Mexico is one of the most extreme cases of ocean pollution. It covers almost 17,000 square kilometres of hypoxic water – where very little or no oxygen is present. Nothing can grow there, as almost all organisms require oxygen to survive. Dead zones are caused by nutrient runoff from the land (such as agricultural fertilisers) that cause an excess of algal growth. When the algae dies, it decomposes and consumes all of the oxygen in the water.

Dead zones occur in various oceans and inland water bodies, shown here with red dots



**Where:** Surrounding Antarctica  
**Ocean:** Southern Ocean

## 8 Coldest

### Welcome to life in the liquid freezer

At the very bottom of the globe, surrounding frozen Antarctica, swirls the untameable Southern Ocean. It's home to some of the fastest winds and tallest waves, and also boasts the largest ocean current (the Antarctic Circumpolar Current) that transports more water than all the world's rivers combined. Temperatures can reach a bitterly cold -2 degrees Celsius, because the ocean's salinity lowers its freezing point.

Animals that live in the Southern Ocean also have to adapt to survive. Extra layers of blubber and super-insulating feathers are just a few adaptations, but one of the most extreme has to be that of the Antarctic icefish. This critter has evolved a type of 'antifreeze' protein to prevent ice crystals forming in its body when the temperature plummets.

**10,000–50,000**

Number of icebergs produced in the Arctic annually

The Southern Ocean is home to the coldest and stormiest waters on Earth

**1,000 YEARS**

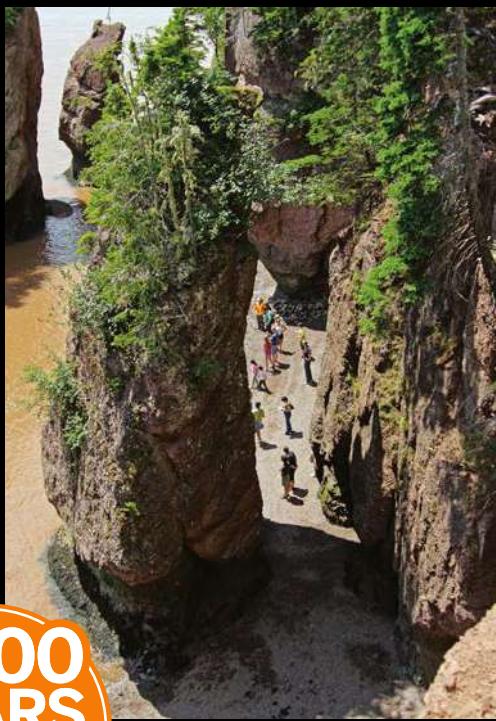
Time for 1m<sup>3</sup> of water to travel around the world's currents

**Where:** Bay Of Fundy, Canada  
**Ocean:** Atlantic Ocean

## 7 Most extreme tides

At the head of the Bay of Fundy, at the right time of the month, the difference in high tide and low tide can be a huge 16 metres. When the tide is this high, the bay fills and empties 100 billion tons of seawater during each tidal cycle. The huge tide is a result of the bay's shape and depth, as the water within the bay oscillates (like water sloshing from one end of a bathtub to another) in sync with tides from the Atlantic.

The Bay of Fundy stretches for 270km along Canada's east coast and is a tourist hotspot

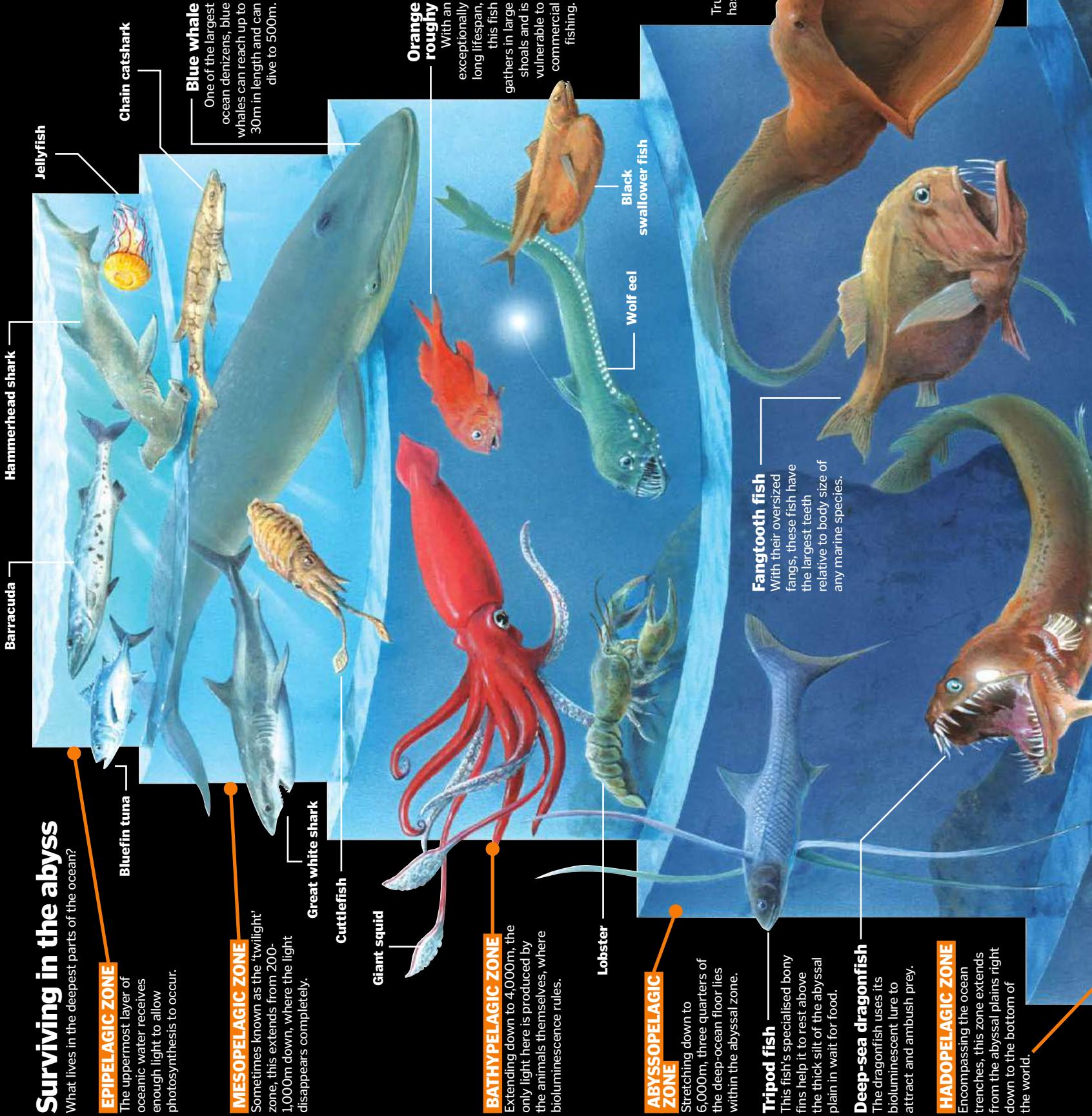




# 9 Deepest

Where: Mariana Trench  
Ocean: Pacific Ocean

Take a breath and dive deeper than Everest is tall





**Supergiant amphipods**  
This super-sized crustacean (related to crabs and lobsters) can be found lurking in the deep ocean trenches.

At the very bottom of the ocean, just shy of 11,000 metres below the surface, sunlight is long gone and all that is left is inky blackness. The Challenger Deep is part of the Mariana Trench, a deep score across the sea floor of the Pacific basin that is formed at a subduction zone, where one tectonic plate disappears beneath another. It is the deepest point in Earth's oceans, and with over ten kilometres of water overhead, the hydrostatic pressure is 1,100 atmospheres – the equivalent of inverting the Eiffel tower and balancing it on your big toe.

The water temperature at the bottom of the Challenger Deep is just above freezing, and the trench is filled with clouds of silt, formed from millions of years of ocean garbage falling from above and slowly rotting away. However, despite the pressure, darkness and coldness of the environment, life still prevails! The deep sea is home to an array of strange and wonderful creatures that survive against all odds, having developed clever mechanisms to deal with the extreme conditions.

The Challenger Deep was first explored in 1960 by Swiss scientist Jacques Piccard and US Navy Lieutenant Don Walsh in the Trieste submersible, which set a record by diving to a depth of just over 10,915 metres. Since that seminal dive there have been multiple attempts by both manned and unmanned vehicles, the most recent made by explorer and film-maker James Cameron, who managed to reach a depth of 10,898 metres in his Deepsea Challenger submarine.

## Hydrothermal vents

Often forming at mid-ocean ridges where tectonic activity is high, hydrothermal vents are cracks and fissures in the Earth's crust where super-heated water escapes into the ocean. The temperature of this water can reach 400 degrees Celsius, but doesn't boil due to the extreme pressure.

Hydrothermal vents can support vast communities of life. The organisms that live around them use chemosynthesis – as opposed to photosynthesis – to survive. The primary producers of a chemosynthetic food chain are microbes that use the chemicals expelled by the vents as the basis to create energy, akin to how plants on land use sunlight.

Seawater filters through the rocks into the crust, becomes super-heated and is expelled through vents

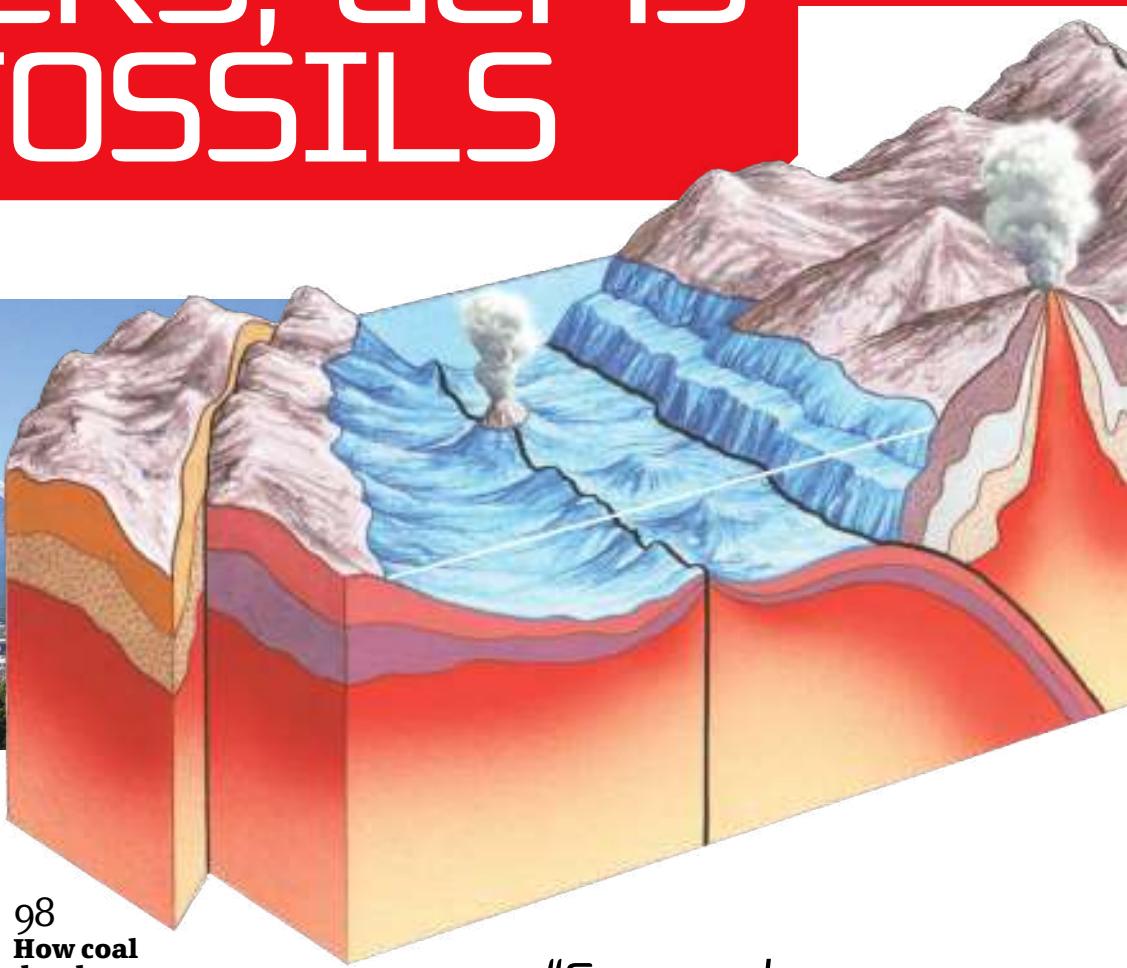


© Corbis



# ROCKS, GEMS & FOSSILS

96  
Mountain formation



90  
Measuring earthquakes

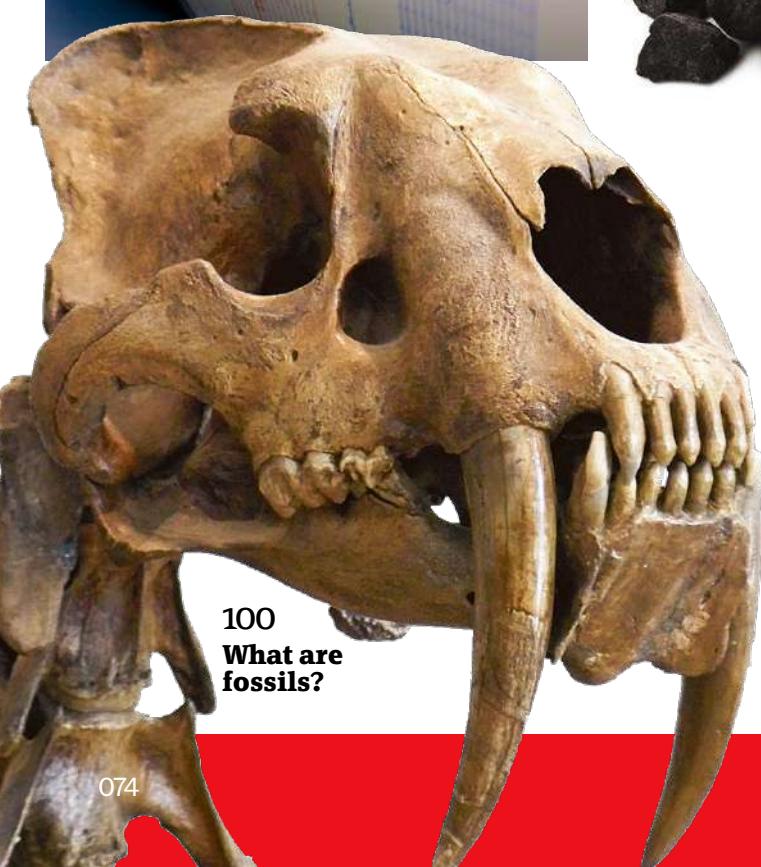


98  
How coal develops

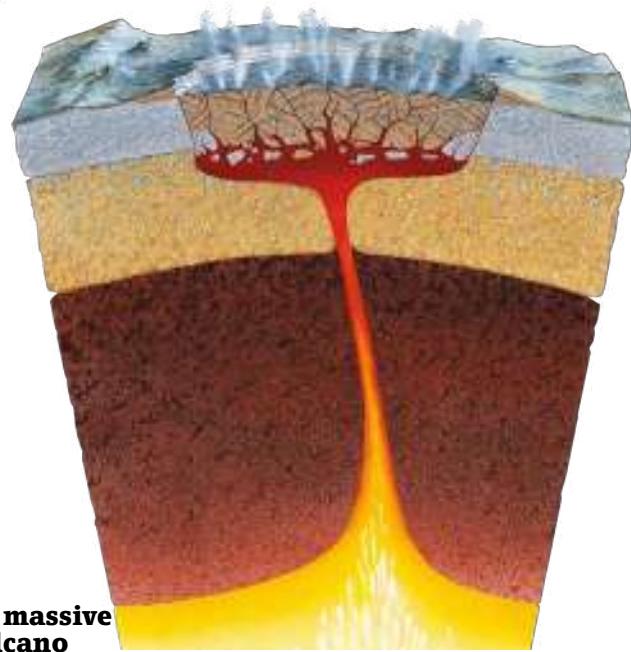


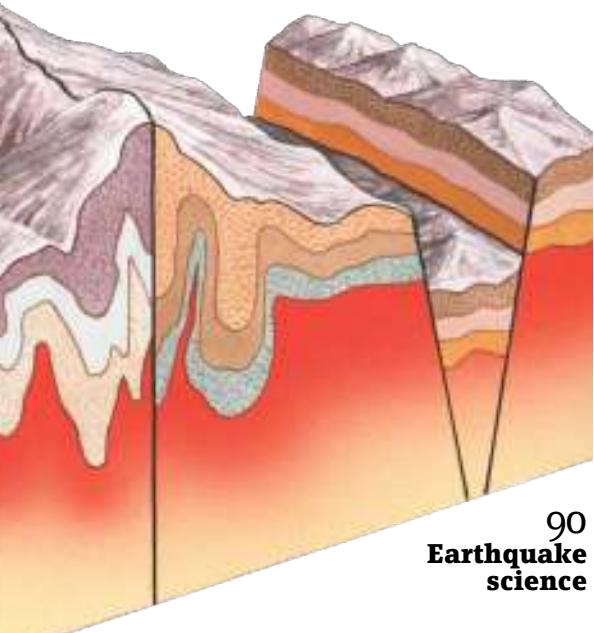
*"Super volcanoes have the potential to destroy civilisation"*

100  
What are fossils?



86  
Get inside a massive supervolcano





90  
**Earthquake science**

**76 Weird world wonders**

Discover the strange geology from around the globe

**86 Super volcanoes**

These timebombs could wipe out entire civilisations

**90 Earthquakes**

What exactly is it that causes these devastating natural hazards?

**96 Mountain formation**

Earth's rising landforms explained

**98 How is coal formed?**

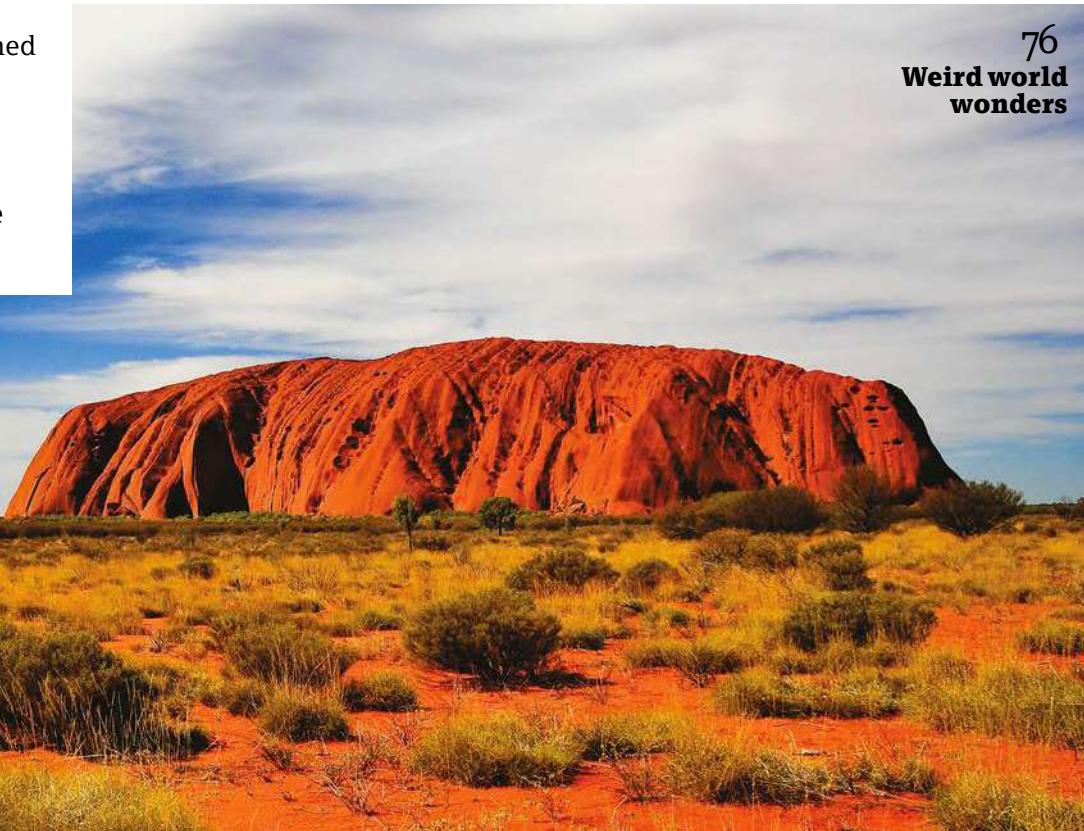
A rock essential to modern life but one that is running out

**100 What are fossils?**

A unique insight into what once lived on Earth



76  
**Weird world wonders**





# WEIRD WORLD WONDERS

The bizarre but beautiful formations that show Earth's geology rocks

## Creating a causeway

How volcanic activity formed 40,000 giant rock pillars

**A**ccording to legend, the stepping stones of the Giant's Causeway were created by the giant Finn McCool, so that he could walk across the Irish Sea from Northern Ireland to Scotland and fight his rival, Benandonner. In reality, they were formed by volcanic activity around 60 million years ago. Back then, the continents of Europe and North America were attached, but soon began to slowly tear away from each other. As this happened, huge cracks in the Earth's crust formed, causing lava to spew up from below. This lava cooled to form layers of basalt rock on the north coast of Northern Ireland. Over time, the rain eroded away the rock to form a valley, into which more lava

flowed. At the top, this lava cooled rapidly, forming a crust that helped to insulate the liquid lava below. As a result, the bottom layer cooled more slowly, causing it to shrink and crack into hexagonal columns. During the most recent ice age, which ended about 11,500 years ago, glaciers eroded the top layer of the rock, exposing the columns beneath. Rising sea levels caused by warmer weather then began to wear them away, creating the varying heights of the columns you can see today.

**Lower basalt**  
Formed by the first volcanic eruptions, these layers are visible as five dark bands of rock in the cliffs.

**Multi-sided**  
Most of the columns are hexagonal, but some have four, five, seven or eight sides.

## Giant's Causeway

This geometric landscape formed over millions of years of geological activity

### Middle basalt

A second phase of volcanic activity poured lava onto the surface, which cooled to form the causeway's columns.

### Upper basalt

Further volcanic activity formed a third layer of basalt. This has since worn away on the causeway but can be seen inland.

*"According to legend, the causeway was created by the giant Finn McCool"*

### A watchful eye

Some columns have been eroded to become completely circular, earning them the nickname 'giant's eyes'.

### Big and small

The columns vary in size depending on their cooling rates. The slower the lava cooled, the larger the columns created.

©Shutterstock/Thinkstock

Hexagonal black basalt columns interlock to form the causeway



## OZ ODDITIES

The Australian outback is home to many strange landmarks

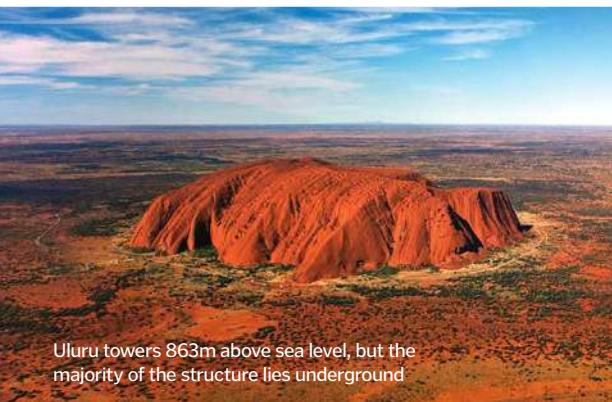
The individual domes of Kata Tjuta formed when rain and groundwater carved deep canyons out of the rock

### Uluru and Kata Tjuta

Standing proud against the flat horizon of the Australian outback are two enormous sandstone and rock formations named Uluru and Kata Tjuta. They may look a little out of place but they have been there for millions of years, forming as a result of geological processes.

#### Flaky surface

Close up, the surface of Uluru is grey, with a coating of red flakes of rock. The flakes' colour is due to the iron in the rock rusting.



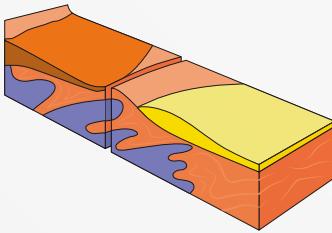
Uluru towers 863m above sea level, but the majority of the structure lies underground



*"They have been there for millions of years, forming as a result of geological processes"*

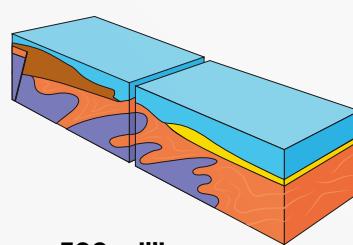
### Rocky history

How did the magnificent Uluru and Kata Tjuta rocks form?



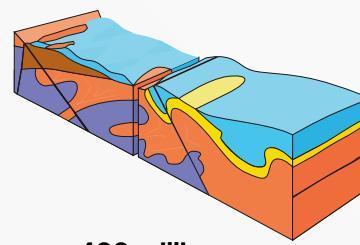
#### 550 million years ago

Rainwater eroded the mountains in the Petermann Ranges, depositing sediment in two fan shapes, one of sand and one of rock, onto the surrounding plain.



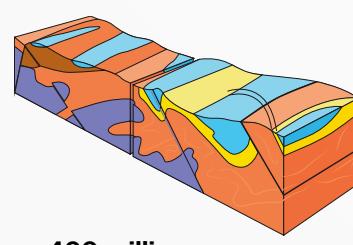
#### 500 million years ago

The area was covered in a shallow sea. A seabed of sand and mud compressed the fans, turning the rock into conglomerate rock, and the sand into arkose sandstone.



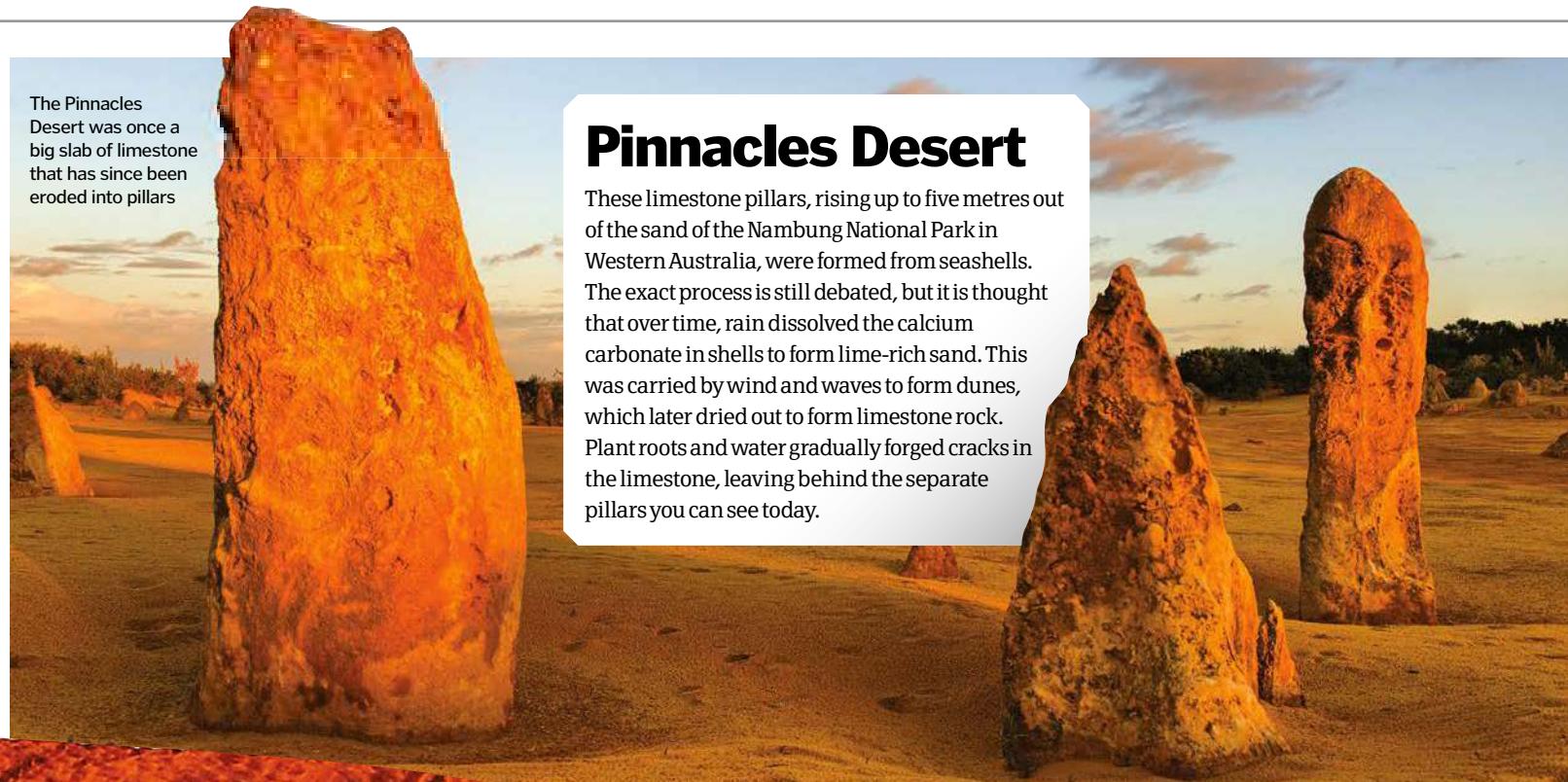
#### 400 million years ago

The sea receded again, and the rocks started to fold and tilt under the immense force of the Earth's shifting tectonic plates.



#### 400 million years ago (continued)

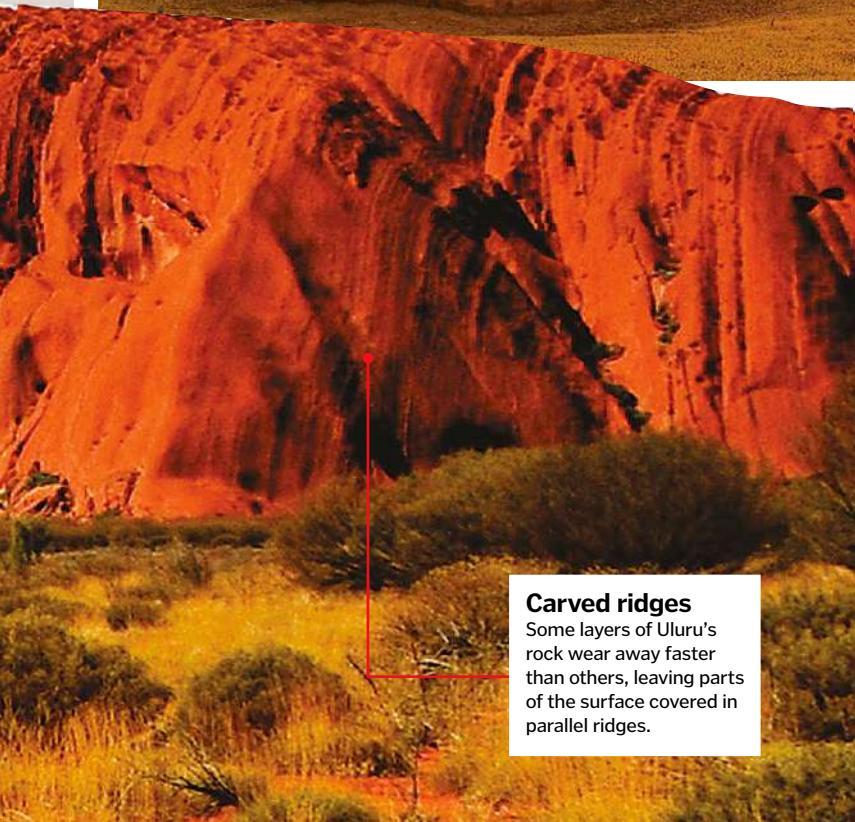
The rocky fan tilted by about 20 degrees, becoming Kata Tjuta. The sandstone fan tilted almost 90 degrees, becoming Uluru.



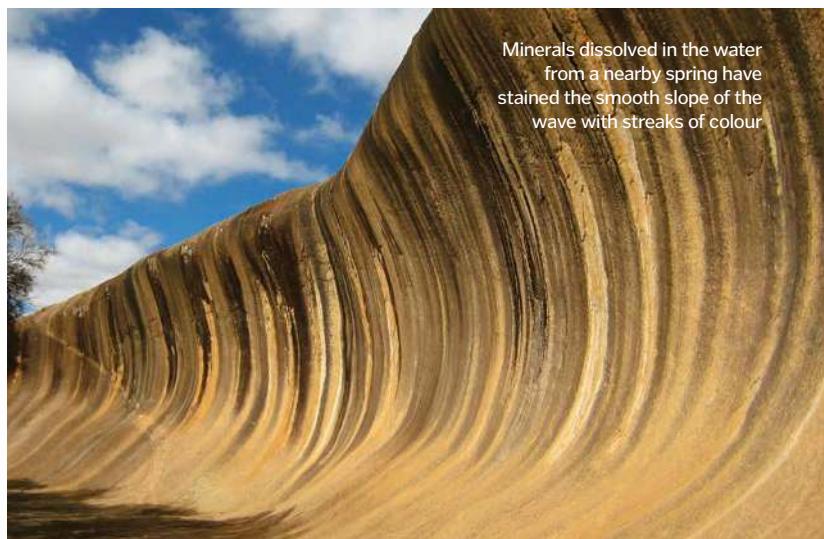
The Pinnacles Desert was once a big slab of limestone that has since been eroded into pillars

## Pinnacles Desert

These limestone pillars, rising up to five metres out of the sand of the Nambung National Park in Western Australia, were formed from seashells. The exact process is still debated, but it is thought that over time, rain dissolved the calcium carbonate in shells to form lime-rich sand. This was carried by wind and waves to form dunes, which later dried out to form limestone rock. Plant roots and water gradually forged cracks in the limestone, leaving behind the separate pillars you can see today.



**Carved ridges**  
Some layers of Uluru's rock wear away faster than others, leaving parts of the surface covered in parallel ridges.

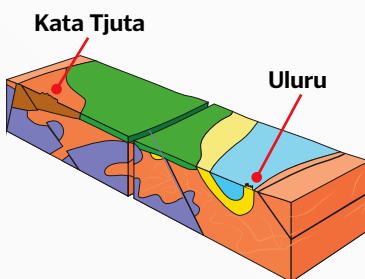


Minerals dissolved in the water from a nearby spring have stained the smooth slope of the wave with streaks of colour

## Wave Rock

This granite rock was buried by soil, exposing the top. As granite does not erode easily, the top remained intact, but as rain moistened the soil below,

it became acidic and dissolved the base of the rock. The soil has since eroded away, exposing the 15-metre-tall overhanging wave.

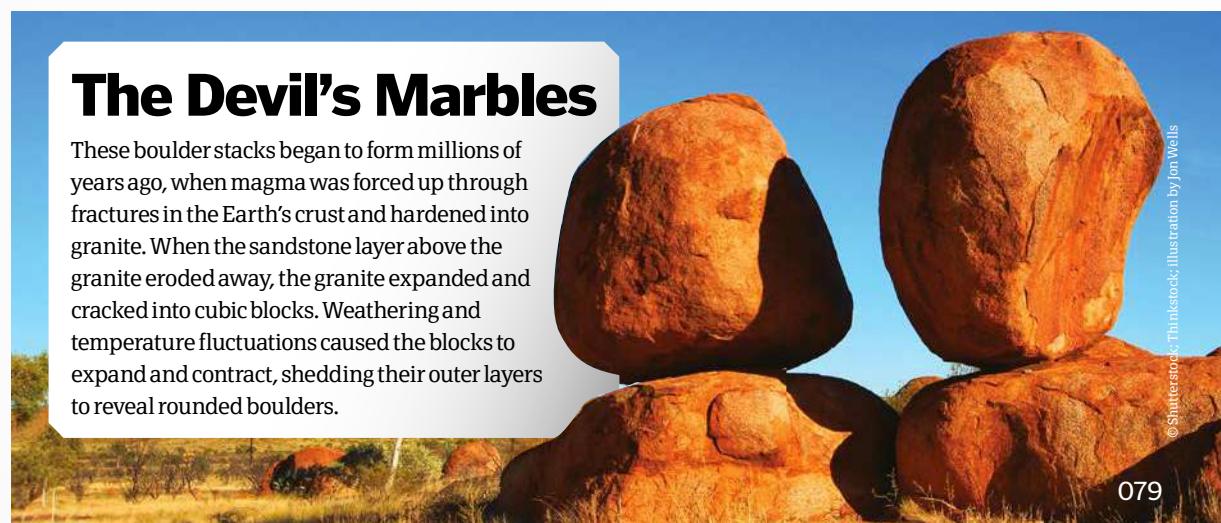


**500,000 years ago**

As the climate became drier, wind-blown sand partly filled the valley between the two slabs of rock that were now protruding from the surface.

## The Devil's Marbles

These boulder stacks began to form millions of years ago, when magma was forced up through fractures in the Earth's crust and hardened into granite. When the sandstone layer above the granite eroded away, the granite expanded and cracked into cubic blocks. Weathering and temperature fluctuations caused the blocks to expand and contract, shedding their outer layers to reveal rounded boulders.





# HOODOOS

How have these enormous and ancient stacks of rock managed to stay standing?

Typically found rising up from the bottom of arid drainage basins or badlands, hoodoos are tall spires that have been carved out of rock over millions of years. They range in height from 1.5 to 45 metres, and are often striped with the different colours of the rock types that make up their layers. It's these layers that help to prevent these seemingly impossibly balanced stacks from collapsing, as hard rock on top protects the softer lower layers from erosion. Although most hoodoos began life as canyon walls, others have formed in a slightly different way. The famous Fairy Chimneys in Turkey's Cappadocia region are the result of volcanic eruptions that rained down ash, which hardened into a soft porous rock. This rock was covered with a layer of basalt, which eroded into mushroom-shaped caps, protecting it from the elements.



## Disintegration

Eventually, the neck of the cone will erode to a point where the cap falls off. The remaining pillar will then disintegrate.



Hoodoos are more abundant in Utah's Bryce Canyon National Park than anywhere else in the world



## Erosion rates

The hoodoos are made up of different rock types, which erode at varying speeds. The thinnest parts are mudstone, which erodes easily.

Some of the Fairy Chimneys in Turkey were turned into homes and churches in Roman times



## How do hoodoos form?

From flooded canyon to rocky pillars, discover how erosion shaped these rock towers



## Empty canyon

A vast lake drains away, leaving behind a canyon with a layer of sediment at the bottom.



## Receding walls

Water seeps out of the lower rocks, taking rock material with it and eroding away the walls.



## Vertical cracks

Acidic rainwater widens cracks, and expands and contracts as it freezes and thaws, eroding the rock further.



## Protective cap

The harder layer of rock on top protects the softer layer beneath it from erosion, forming tall hoodoos.

# ICE TOWERS

The amazing ice sculptures built by heat below the surface

It may look like a crooked chimney spewing smoke into the cold Antarctic air, but there's no fire to be found inside this strange structure. Instead, you'll find a cave, carved out of the ice by the heat from the nearby Mount Erebus volcano. The steam rising from these caves instantly freezes as it hits the sub-zero air above, forming a hollow tower of ice above. The scientific name for these features is ice fumaroles – a fumarole being any volcanic vent that ejects gas or steam. They can be found all over the world, and even on Mars, but only a few places are cold enough to turn their emissions to ice.

*"Steam from the caves instantly freezes as it hits the sub-zero air above"*



## A land of ice and fire

Despite being located in the centre of a stationary tectonic plate, Antarctica still manages to be a hotbed of volcanic activity. This is all down to the West Antarctic Rift, an area where the tectonic plates are slowly moving apart. Along this rift, the Earth's crust has thinned, allowing magma to rise to the surface and create enormous volcanoes. While many of the volcanoes are now extinct, others are still ejecting hot gas and lava, with the most active being Mount Erebus on Ross Island. Mount Erebus is one of only a few volcanoes to have an open lava lake. While the central crater on most volcanoes is covered with a solid slab of cooled molten rock, the one on this volcano is uncovered, exposing the hot magma inside. Several low-level eruptions occur every day, ejecting scorching lava bombs onto the surrounding landscape as a result.

Mount Erebus is the second tallest volcano in Antarctica, and the most southerly active volcano on Earth





# DEVILS TOWER

The magnificent American monument with mysterious origins

Among the pine forests of Crook County, Wyoming, stands an enormous lump of rock reaching high up into the sky. Known as Devils Tower, it is so awe-inspiring that in 1906, President Theodore Roosevelt established it as the United States' first national monument, but no one quite knows how it formed. What we do know is that it is made from phonolite porphyry, an igneous rock that is formed when magma cools and crystallises. In this case, as the magma cooled, it also contracted, cracking the rock into the polygonal columns that now make up the Tower. Most geologists agree that the rock formed when magma rose up into the surrounding sedimentary rock, but there are three possible theories for how this happened.

## Columns

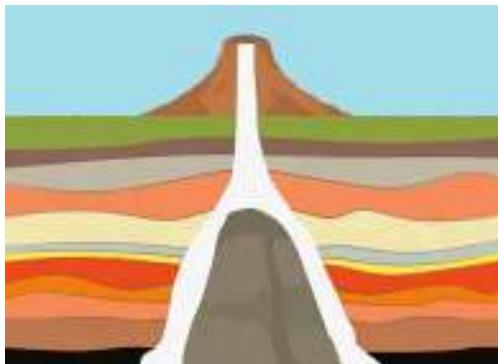
The Tower's almost vertical columns were formed as magma cooled and condensed into igneous rock.

## Erosion continues

The Tower is still eroding today, and the land surrounding it is littered with rocks and rubble that have fallen from the structure.

## Formation theories

Three popular ideas of how Devils Tower came to be



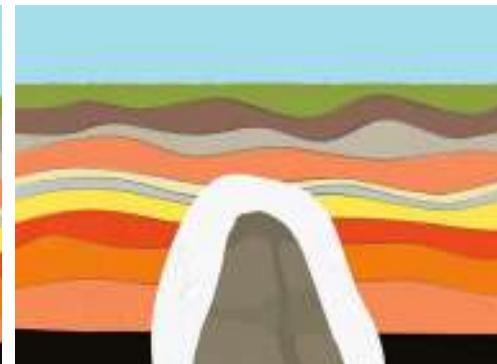
### Theory 1 - Volcanic plug

The rock is the neck of an extinct volcano or a plug that lay beneath it. Although there is no evidence of volcanic activity, such as ash or lava flows, in the area, this material could have simply eroded away.



### Theory 2 - Laccolith

The Devils Tower is a laccolith, a large, mushroom-shaped mass of igneous rock, which spreads between the layers of sedimentary rocks beneath the Earth's surface. The rounded bulge on top has eroded away.



### Theory 3 - Stock

Magma beneath the Earth's surface cooled and crystallised to form the lump of rock you can see today. Over time it was exposed by erosion wearing away the rock above it.



# THE WAVE

Arizona's sweeping rock of many colours was once a dinosaur stomping ground

This spectacular wave structure started to form 190 million years ago when dinosaurs walked the Earth, and their footprints can still be seen in the rock today. The Wave began as sand dunes, which were compacted and solidified to become sandstone. The smooth undulating shape is the result of very slow erosion, originally caused by the flow of water, which deposited various minerals into the rock to create the colourful stripes that swirl through it. When the water dried up, wind erosion took over, and continues to carve the rock to this day.

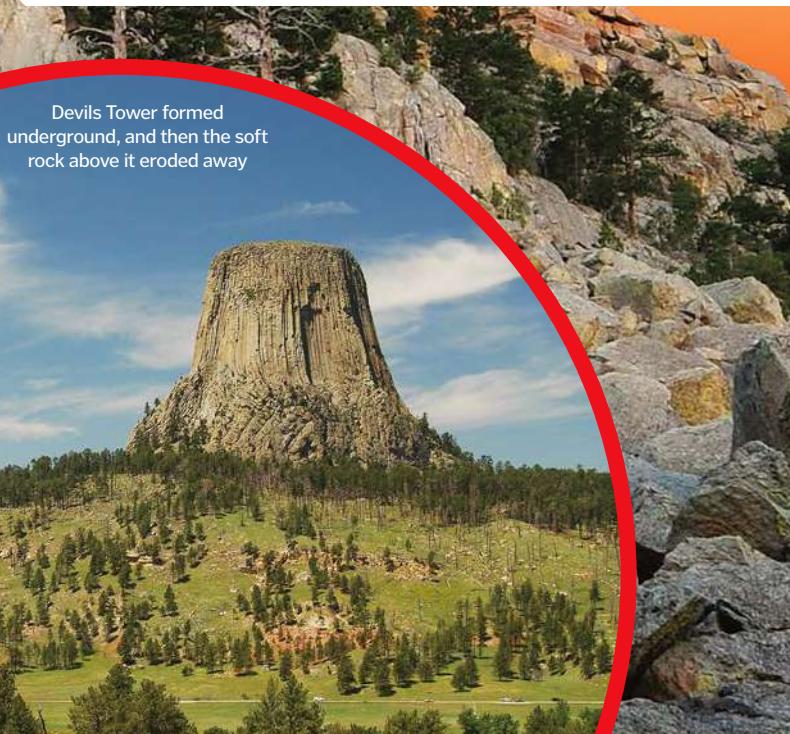
To help protect the soft rock of the Wave, only 20 visitors are permitted each day

## SAND TUFA

The bizarre cauliflower formations that sprout when conditions are just right

They may look like the flowering head of a popular vegetable, but these alien-like structures are actually known as tufa. They form underwater in alkaline lakes, such as California's Mono Lake, at the site of freshwater springs rich in calcium. When the calcium comes into contact with carbonates in the surrounding water, calcium carbonate forms, also known as limestone. The limestone settles on the lake bed, and as more and more is deposited, a tower begins to grow. Most of these structures remain obscured by water, but in lakes where the water levels have dropped, they become visible for all to see.

Mono Lake in California has one of the most impressive tufa displays



Devils Tower formed underground, and then the soft rock above it eroded away



# CAVE OF CRYSTALS

The spectacular secret treasures that have been growing beneath Mexico for 500,000 years

When miners broke through the wall of a Mexican silver mine, 300 metres underground in the year 2000, they could never have expected the site that greeted them. Enormous, translucent beams of crystal towered above them, criss-crossing from either side of a sweltering cave. Normally flooded with water, the mining company's pumping operations had made the cave accessible to humans for the first time, uncovering the largest natural-grown crystals ever found.

The reason why the crystals had been able to grow so large is because of the precise conditions inside the cave. Lying above a magma chamber on an ancient fault line, the water inside the cave, which was rich in the mineral anhydrite, had been kept at a steady temperature of 58 degrees Celsius. At this temperature, anhydrite slowly dissolves into gypsum, a soft mineral that grows into crystals. These conditions have prevailed for the past 500,000 years, allowing the gypsum crystals to grow to their impressive heights, but have also made the cave inhospitable. The high temperature and humidity means that humans can only survive inside for short periods of time, even when wearing suits lined with ice and carrying a breathing system that feeds cold air into the lungs.

With studies of the crystals still ongoing, there is currently some debate about what to do when the Naica mine closes. Geologists must decide whether to continue pumping out the water to allow access to the cave, or let it flood again so that the crystals can continue to grow.

The Cave of Crystals is buried beneath the Naica mountain in the Chihuahuan Desert of Mexico

*"Humans can only survive inside the cave for short periods of time"*

## Ancient bacteria

Researchers took samples of some of the crystals in order to identify any bacteria that lived in these extreme conditions.

## Crystal breeding

A magma chamber beneath the cave heated the mineral-rich water to a stable 50°C, providing ideal conditions for crystal growth.



## Cave by numbers

Unbelievable stats about the deadly cave of wonders

**11m**

THE LENGTH OF THE TALLEST CRYSTAL, ALMOST THE HEIGHT OF THREE DOUBLE-DECKER BUSES

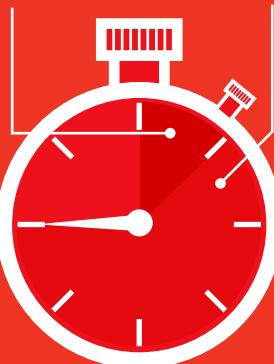


**55 tons**

THE WEIGHT OF THE LARGEST CRYSTAL, EQUIVALENT TO NINE AFRICAN ELEPHANTS

**10min**

The length of time you can survive in the cave without any equipment



**2hrs**

The length of time you can survive in the cave with proper equipment

**9x27m**

The size of the Cave of Crystals - slightly larger than a tennis court

**90-100%**  
HUMIDITY INSIDE THE CAVE

**20 KG**  
Weight of the cooling suit that must be worn inside the cave



**50 °C**



Deadlier than an asteroid strike, these massive formations have the potential to destroy civilisation

# SUPER VOLCANOES

**M**any people will remember the airport chaos of spring 2010 when Eyjafjallajökull, one of Iceland's largest volcanoes, erupted after almost two centuries of peaceful slumber.

But though it might be hard to believe, considering the mammoth amount of disruption that it caused, the Icelandic eruption was tiny compared to a super-eruption's devastating power. The Eyjafjallajökull event measured a mere 4 on the Volcanic Explosivity Index (VEI), which rates the power of eruptions

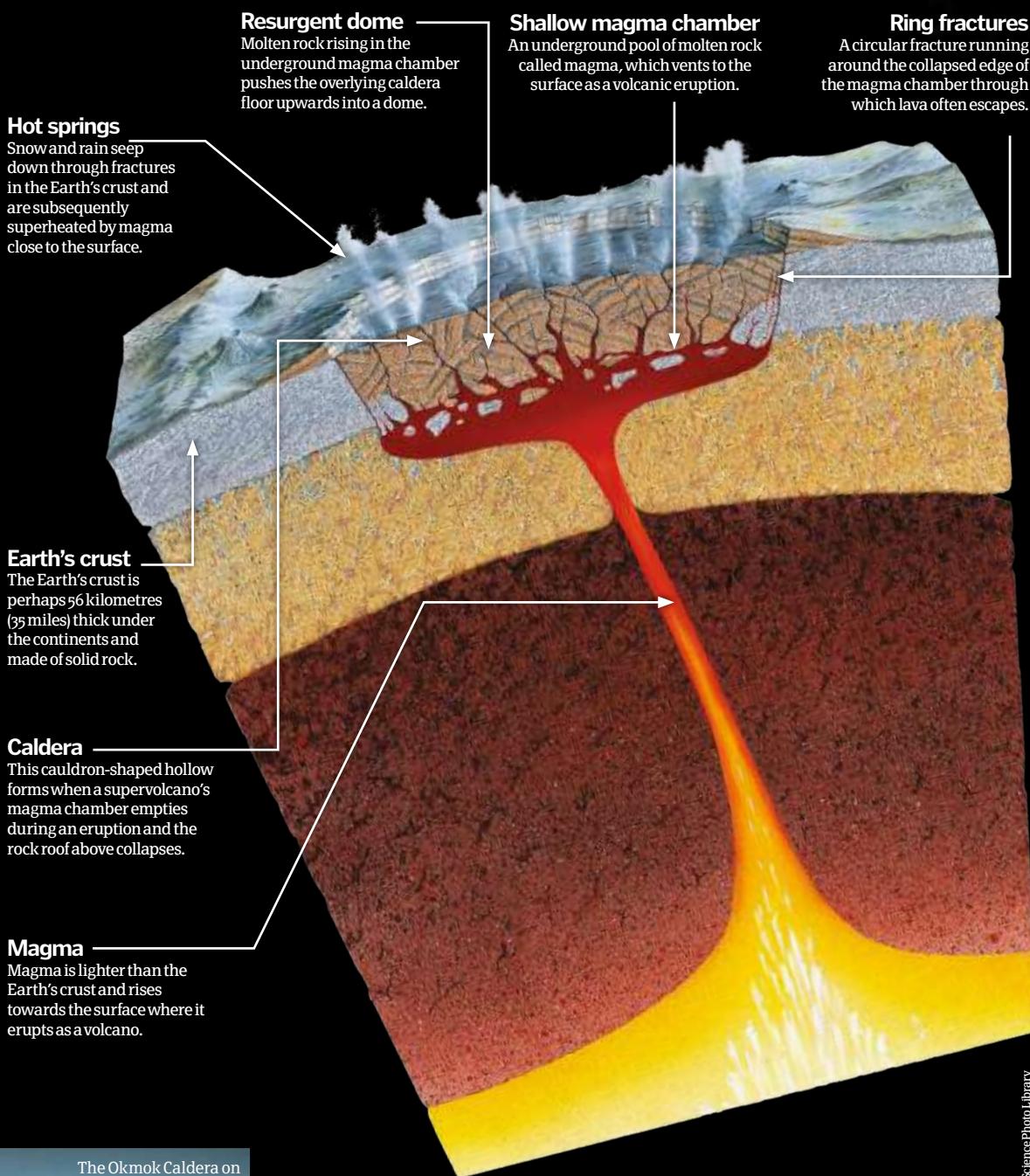
on an eight-point scale. A massive VEI 8 blast, on the other hand, would threaten human civilisation. Such a super-eruption would spew out more than 1,000 cubic kilometres (240 cubic miles) of ejecta – ash, gas and pumice – within days, destroying food crops, and changing the world climate for years.

A super-eruption hasn't happened in recorded history, but they occur about every 10,000-100,000 years. That's five times more often than an asteroid collision big enough to threaten humanity. Scientists say there's no

evidence that a super-eruption is imminent, but humans will face nature's ultimate geological catastrophe one day.

A supervolcano is simply a volcano that's had one or more super-eruptions in its lifetime. Supervolcanoes are typically active for millions of years, but wait tens of thousands of years between major eruptions. The longer that they remain dormant, the bigger the super-eruption. They typically erupt from a wide, cauldron-shaped hollow called a caldera, although not every caldera houses a future supervolcano.

# Inside a supervolcano



## Predicting the next super-eruption

Volcanologists at the Yellowstone Volcanic Observatory are among those studying supervolcanoes. They hope to have decades or centuries to prepare for a super-eruption. Warning signs could include the ground bulging and cracking as hot rock muscles to the surface, an increase in small eruptions and earthquakes, and changes in the gases escaping the ground.

Scientists analyse earthquakes by measuring ground vibration with seismometers. Earthquakes often increase before eruptions as magma and gas force

through underground fractures, causing rocks to break. The ground historically rises before eruptions due to upwelling magma. For example, the north flank of US volcano Mount St Helens rose by a staggering 80 metres (262 feet) in 1980.

Scientists constantly keep track of Earth movements using networks of satellite GPS receivers. Like GPS in cars, these monitor the receiver's location on the ground. Another satellite technology, InSAR, measures ground movement over large areas once or twice annually.



### 8. CALDERA FORMS

**DAYS**

The rock cylinder inside the ring fractures and plunges into the emptied magma chamber. Gas and lava spurt from the fractures.

### 7. DEADLY CLOUDS

**DAYS**

The fractures join into a ring of erupting vents. Toxic ash and fragment clouds race downhill at snow avalanche speed.

### 6. SUPER-ERUPTION

**HOURS TO DAYS**

The expanding gases act like bubbles of pop in a shaken bottle, flinging lava and rock high into the atmosphere.

### 5. MAGMA CHAMBER RUPTURES

**HOURS TO DAYS**

Vertical fractures in the swollen crust breach the magma chamber, allowing pressurised, gas-filled magma to escape to the surface as lava.

### 4. WARNING SIGNS INCREASE

**WEEKS TO CENTURIES**

Warning signs of a super-eruption may include swarms of earthquakes and the ground rapidly swelling up like baking bread.

### 3. MAGMA CHAMBER EXPANDS

**TENS OF THOUSANDS OF YEARS**

Supervolcano magma chambers can grow for tens of thousands of years because they are surrounded by flexible hot rock.

### 2. PRESSURE BUILDS

**TENS OF THOUSANDS OF YEARS**

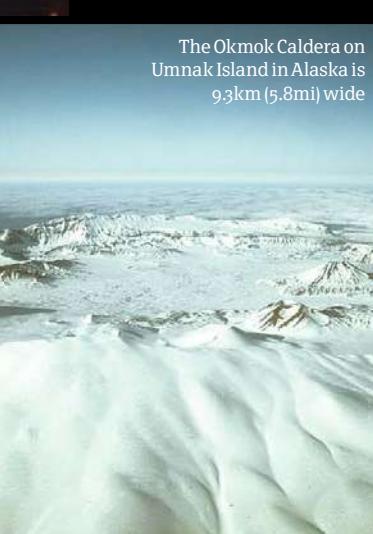
As magma accumulates in a chamber, the pressure builds and the cavity expands. Fractures begin to form in the chamber roof.

### 1. MAGMA RISES

**TIME: MILLIONS OF YEARS**

Magma forms when rock deep in the Earth liquefies and pushes through the solid crust towards the surface.

## COUNTDOWN TO ERUPTION





This artist's illustration reveals the smoke and ash that could result from a supervolcanic eruption at Yellowstone



© Science Photo Library

## The fallout following a super-eruption

A supervolcano erupting today could threaten human civilisation. Clouds of molten rock and iridescent gas travelling three times faster than motorway cars would obliterate everything within 100 kilometres (60 miles) of the blast. Dust would spread thousands of kilometres, blotting out the Sun. People's unprotected eyes, ears and noses would fill with needle-like ash, which can pop blood vessels in the lungs and kill by suffocation.

Up to 0.5 metres (1.6 feet) of ash could rain down each hour, collapsing roofs, poisoning water supplies and halting transport by clogging car and aircraft engines; just a few centimetres of ash can disrupt agriculture. The 1815 eruption of Indonesia's Mount Tambora caused the 'year without a summer' when European harvests failed, bringing famine and economic collapse. Financial markets could be disrupted and countries swamped by refugees. Some scientists say a Yellowstone super-eruption could render one-third of the United States uninhabitable for up to two years.

The supervolcano simmering under Yellowstone National Park in the USA is probably the world's most studied, but super-eruptions occur so rarely that they remain a mystery. We know of 42 VEI 7 and VEI 8 eruptions in the last 36 million years, but much of the debris from these ancient super-eruptions has worn away. Eruptions like these take place at irregular intervals and scientists are unsure what triggers them.

Supervolcanoes, like all volcanoes, occur where molten or partly molten rock called magma forms and erupts to the Earth's surface. All supervolcanoes break through the thick crust that forms the continents. The Yellowstone caldera sits on a hot spot, a plume of unusually hot rock in the solid layer called the mantle that lies below the Earth's crust. Blobs of molten mantle rise from the hot spot towards the surface and melt the crustal rocks.

Other supervolcanoes like Lake Toba in Sumatra, Indonesia, lie on the edges of the jigsaw of plates that make

up the Earth's crust. Near Sumatra, the plate carrying the Indian Ocean is being pushed underneath the crustal plate carrying Europe. As it descends, the ocean plate melts to form magma.

Vast quantities of magma are needed to fuel a super-eruption. Some scientists believe that supervolcanoes are 'super' because they have gigantic, shallow magma chambers that can hold volumes of up to 15,000 cubic kilometres (3,600 cubic miles) and grow for thousands of years. Magma chambers are underground pools of accumulated magma that erupt through cracks to the surface. Volcanoes with smaller chambers expel magma before enough pressure builds for a supersized event.

Some scientists speculate that hot, flexible rocks surround supervolcano magma chambers, allowing them to swell to accommodate more magma. The rocks are kept malleable by blobs of magma repeatedly welling up from below.

A super-eruption starts when the pressurised magma explodes through

fractures in the chamber roof. The eruption is violent because supervolcano magma is rich in trapped gas bubbles, which expand and burst as it abruptly depressurises; the eruption is akin to uncorking a champagne bottle. The magma is also sticky and unable to flow easily because it's made partly from melted continental crust. This is in contrast to a volcano such as Mauna Loa in Hawaii, which gently pours out lava because its magma is fluid and contains little gas.

Hot fragments and gas soar to heights of more than 35 kilometres (22 miles) and spread in the atmosphere. Some of the fragments drift down and blanket the ground like snow. Other hot fragments rush downhill for hundreds of square kilometres at speeds exceeding 100 kilometres per hour (62 miles per hour) as toxic, ground-hugging pyroclastic flows. The magma chamber rapidly drains during the super-eruption, causing the roof above to sink into the empty space to (re-)form a caldera.

## Comparison of eruption volumes

VEI 8 / Toba  
74,000 yrs ago  
2,800km<sup>3</sup> (that's 380 times the volume of Loch Ness)

VEI 8 / Yellowstone Huckleberry Ridge  
2.1m yrs ago  
2,450km<sup>3</sup>

VEI 8 / Yellowstone Lava Creek  
640,000 yrs ago  
1,000km<sup>3</sup>

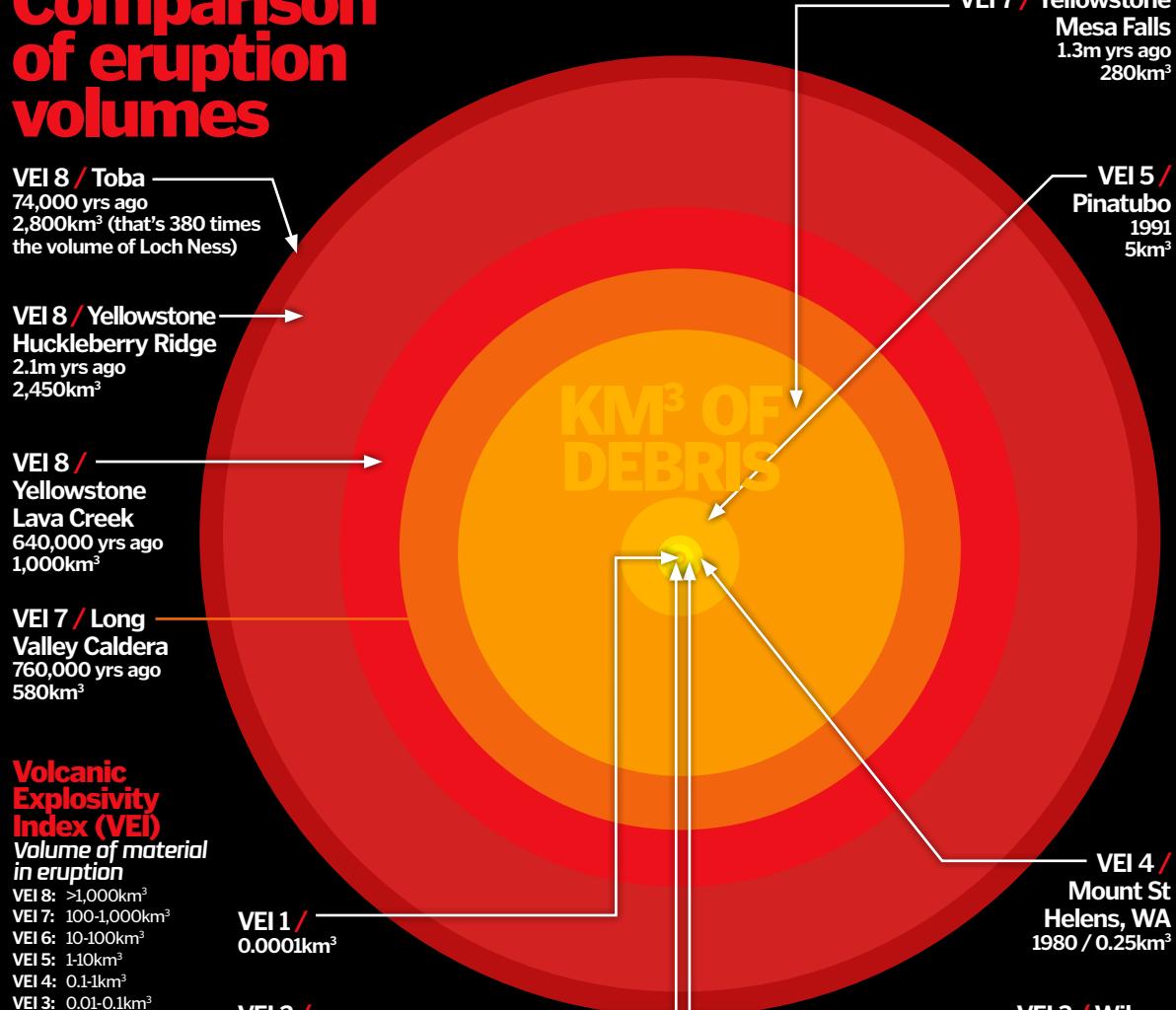
VEI 7 / Long Valley Caldera  
760,000 yrs ago  
580km<sup>3</sup>

**Volcanic Explosivity Index (VEI)**  
Volume of material in eruption  
VEI 8: >1,000km<sup>3</sup>  
VEI 7: 100-1,000km<sup>3</sup>  
VEI 6: 10-100km<sup>3</sup>  
VEI 5: 1-10km<sup>3</sup>  
VEI 4: 0.1km<sup>3</sup>  
VEI 3: 0.01-0.1km<sup>3</sup>  
VEI 2: 0.001-0.01km<sup>3</sup>  
VEI 1: 0.00001-0.001km<sup>3</sup>  
VEI 0: <0.00001km<sup>3</sup>

VEI 2 / Lassen Peak, CA  
1915 / 0.006km<sup>3</sup>

VEI 1 / 0.0001km<sup>3</sup>

VEI 3 / Wilson Butte Inyo Craters, CA  
1,350 yrs ago / 0.05km<sup>3</sup>



## VOLCANOES VS SUPERVOLCANOES

*The explosive battle*

### TYPICAL VOLCANO

### TYPICAL SUPERVOLCANO

#### FOOTPRINT

Volcanoes vary, but a typical shield volcano might be 5.6km (3.5mi) across. The crater – equivalent to a caldera – of Mount St Helens, USA, is about 3.2km (2mi) wide.

Bigger calderas produce larger eruptions, meaning most supervolcanoes cover vast areas. Lake Toba is 90km (56mi) long and lies in such a caldera.

#### HEIGHT

Normal volcanoes are cone-shaped mountains perhaps 1km (3,280ft) high. Mount St Helens, for example, stands 635m (2,084ft) above its crater floor.

Supervolcanoes have 'negative' topography: they erupt from smouldering pits. Lake Toba, which lies in a supervolcano caldera, is over 0.5km (0.3mi) deep.

#### VOLUME

Typical volcanoes have smaller magma chambers. The magma chamber of Mount St Helens, for example, has a volume of just 10–20km<sup>3</sup> (2.4–4.8mi<sup>3</sup>).

Yellowstone's magma chamber and caldera are similar in width. The chamber is 60 x 40km (37 x 25mi) wide, and 5–16km (3–10mi) below the surface.

#### EJECTA

Even huge volcanoes produce comparatively little debris; eg Yellowstone's super-eruptions were up to 2,500 times bigger than the 1980 St Helens blast.

Super-eruptions eject more than 1,000km<sup>3</sup> (240mi<sup>3</sup>) of debris. They also spew at least 10<sup>12</sup> tons of magma: more than the mass of 50 billion cars.

#### DAMAGE

A few eruptions, like Mt Tambora in 1815, changed global climate, but most of the 20 volcanoes erupting as you read this affect only their immediate vicinity.

A Yellowstone eruption could lower Earth's average temperature by 10°C (18°F) for ten years. Within 1,000km (621mi) of the blast, 90 per cent of people could die.

A super-eruption took place in Sumatra 74,000 years ago, forming the planet's largest volcanic lake in the process: Lake Toba



## Yellowstone's restless giant

Beneath Yellowstone National Park bubbles an active supervolcano. A magma chamber, lying as close as eight kilometres (five miles) to the surface in places, fuels the park's 10,000 jewel-coloured hot springs, gurgling mud pools, hissing steam vents and famous geysers like Old Faithful. The 8,897-square-kilometre (3,435-square-mile) park includes the volcano's caldera, which spans 4,400 square kilometres (1,750 square miles); that's big enough to cover the emirate of Dubai.

The supervolcano is fuelled by a 'hot spot', a plume of hot rock rising from hundreds of kilometres below the Earth's surface. Hot spots act like gigantic Bunsen burners, driving catastrophic eruptions by melting the rocks above them. Scientists remain uncertain why hot spots form; they're not found at the edge of Earth's crustal plates and most volcanic activity happens where these plates jostle against one another. Since the hot spot formed around 17 million years ago, it has produced perhaps 140 eruptions. The

North American crustal plate has slid southwest over the stationary hot spot like a belt on a conveyor leaving a 560-kilometre (350-mile) string of dead calderas and ancient lava flows trailing behind.

There have been three super-eruptions since Yellowstone moved over the hot spot: 2.1 million, 1.3 million and 640,000 years ago. Each eruption vented enough magma from the volcano's storage reservoir to collapse the ground above into a caldera. The first and largest eruption created the Huckleberry Ridge Tuff, more than 2,450 cubic kilometres (588 cubic miles) of volcanic rock made of compacted ash. The eruption blasted a huge caldera perhaps 80 x 65 kilometres (50 x 40 miles) in area and hundreds of metres deep across the boundary of today's national park. The most recent caldera-forming eruption blanketed much of North America in ash and created today's Yellowstone Caldera. Hot gas and ash swept across an area of 7,770 square kilometres (3,000 square miles).



### Six known supervolcanoes

- 1 Lake Toba, Sumatra, Indonesia
- 2 Long Valley, California
- 3 Lake Taupo, New Zealand
- 4 Valles Caldera, New Mexico
- 5 Aira Caldera, southern Japan
- 6 Yellowstone National Park, United States





# EARTHQUAKES

## What causes these devastating natural hazards and what are we doing to predict and prepare for them?

**E**arthquakes are one of our planet's most destructive natural hazards, with the ability to flatten entire cities, trigger enormous tsunamis that wash away everything in their path, and cause a devastating loss of life.

Part of an earthquake's immense power lies in its unpredictability, as a huge quake can strike with very little warning, giving those nearby no time to get to safety. Though we don't know when they will occur, we can predict where, thanks to our knowledge of plate tectonics.

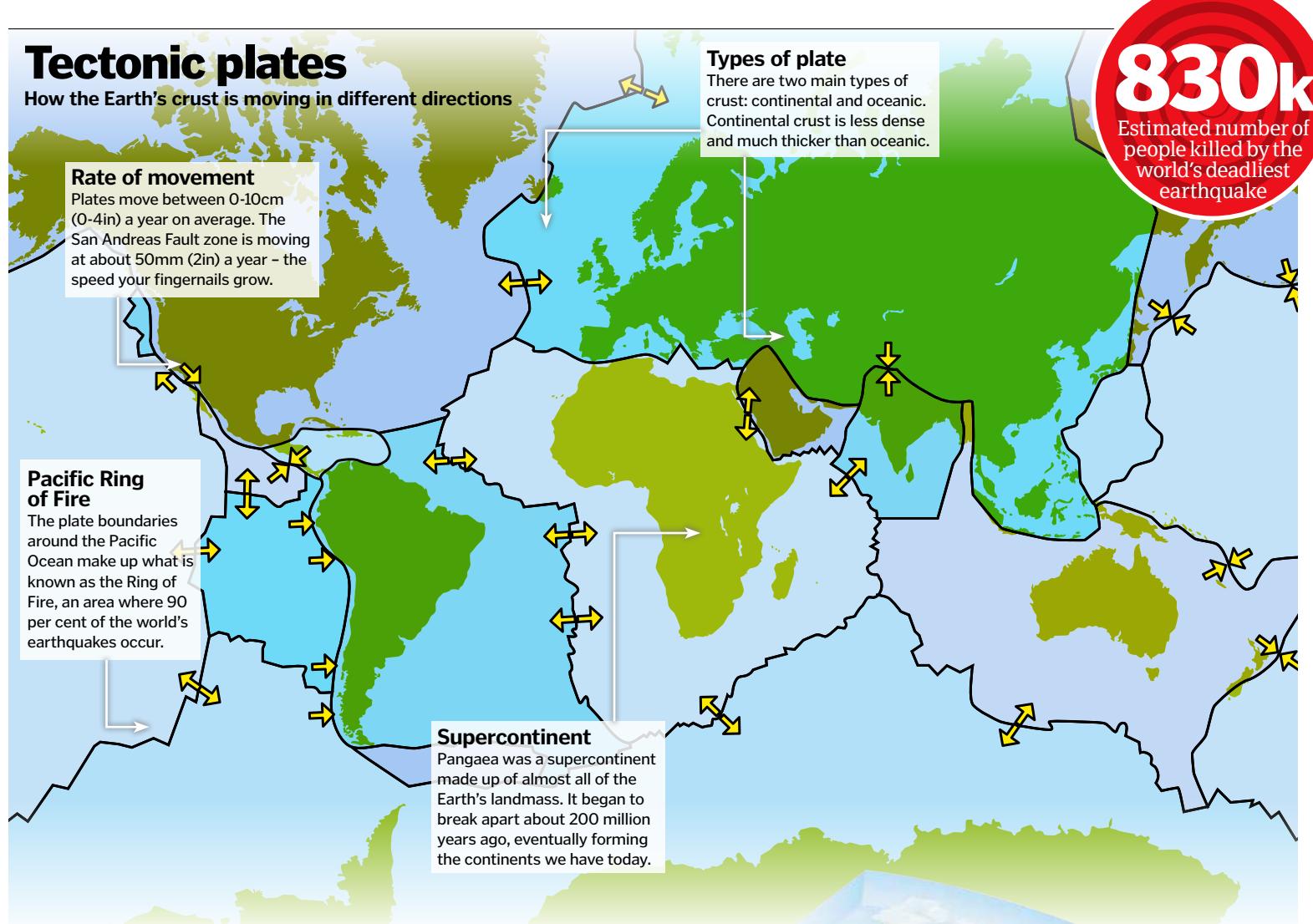
The thin top layer of the Earth, known as the crust, is divided into several plates that are constantly moving. This is caused by heat from

the core of the Earth creating convection currents in the mantle just below the crust, which shifts the plates in different directions.

As the plates move, they collide, split apart or slide past each other along the plate boundaries, creating faults where the majority of earthquakes occur. At divergent or constructive plate boundaries the plates are moving apart, causing normal faults that form rift valleys and ocean ridges. When plates move toward each other along convergent or destructive plate boundaries, they create a reverse or thrust fault, either colliding to form mountains or sliding below the other in a process known as subduction. The third

type is a conservative or transform plate boundary, and involves the two parallel plates sliding past each other to create a strike-slip fault.

Being able to identify these fault lines tells us where earthquakes are most likely to occur, giving the nearby towns and cities the opportunity to prepare. Although the secondary effects of an earthquake, such as landslides and fires from burst gas lines, can be fatal, the main cause of death and destruction during earthquakes is usually the collapse of buildings. Therefore, particularly in developed parts of the world, structures near to fault lines are built or adapted to withstand violent shock waves. The



surrounding population will usually carry out regular earthquake drills, such as The Great California ShakeOut, that gives people a chance to practise finding cover when a quake eventually hits. Unfortunately, many poorer areas cannot afford to be so well prepared, and so when an earthquake strikes, the resulting destruction is often even more devastating and the death toll is usually much higher.

However, our knowledge of how earthquakes happen and the development of new technologies are helping us to find potential methods for predicting when and where the next one will strike. Scientists can currently make general guesses about when an earthquake may occur by studying the history of seismic activity in the region and detecting where pressure is building along fault lines, but this only provides very vague results so far. The ultimate goal is to be able to reliably warn people of an imminent earthquake early enough for them to prepare and minimise the loss of life and damage of property. Until then, being under the constant threat of an impending earthquake is unfortunately part of everyday life for those living along the Earth's constantly active fault lines.

## The Earth's structure

Cut through the different layers of our planet

### Crust

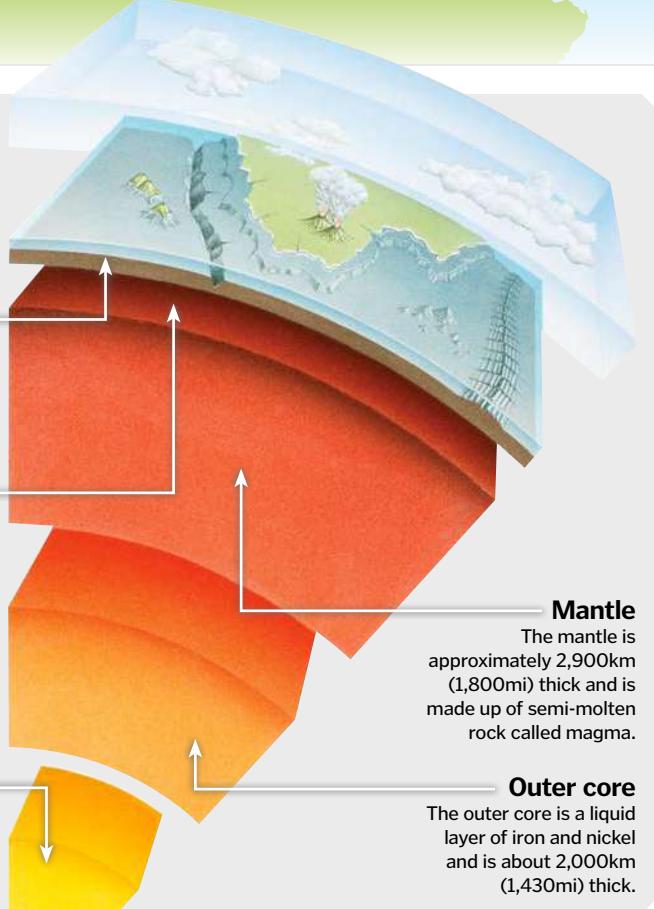
The crust is the rocky outer layer of the Earth and is 40km (25mi) thick on average.

### Lithosphere

The lithosphere, which is about 100km (62mi) deep in most places, includes the harder upper portion of the mantle and the crust.

### Inner core

The inner core is made of solid nickel and iron, with temperatures of up to 5,500°C (9,930°F).





# Anatomy of an earthquake

## How earthquakes are caused and shake the ground beneath our feet

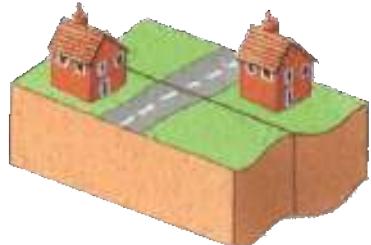
Earthquakes are caused by the build-up of pressure that is created when tectonic plates collide. Eventually the plates slip past each other and a huge amount of energy is released, sending seismic waves through the ground. The point at which the fracture occurs is often several kilometres underground and is known as the focus or hypocentre. The point directly above it on the surface is the epicentre, and this is where most of the damage is caused. Earthquakes have different characteristics depending on their type of fault line, but when they occur underwater, they can sometimes trigger enormous destructive waves called tsunamis.

## How earthquakes occur

The build-up of pressure that causes the ground to move and shake

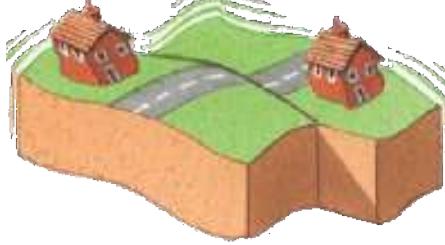
### Friction causes pressure

As the tectonic plates are pushed past or into each other, friction prevents them from moving and causes a build-up of immense pressure.



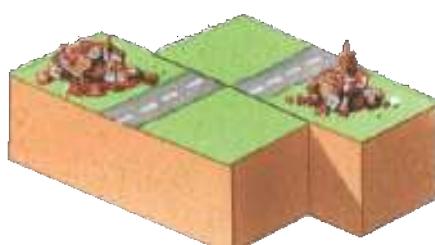
### Energy is released

When the pressure finally overcomes the friction, the plates will suddenly fracture and slip past each other, releasing energy and causing seismic waves.



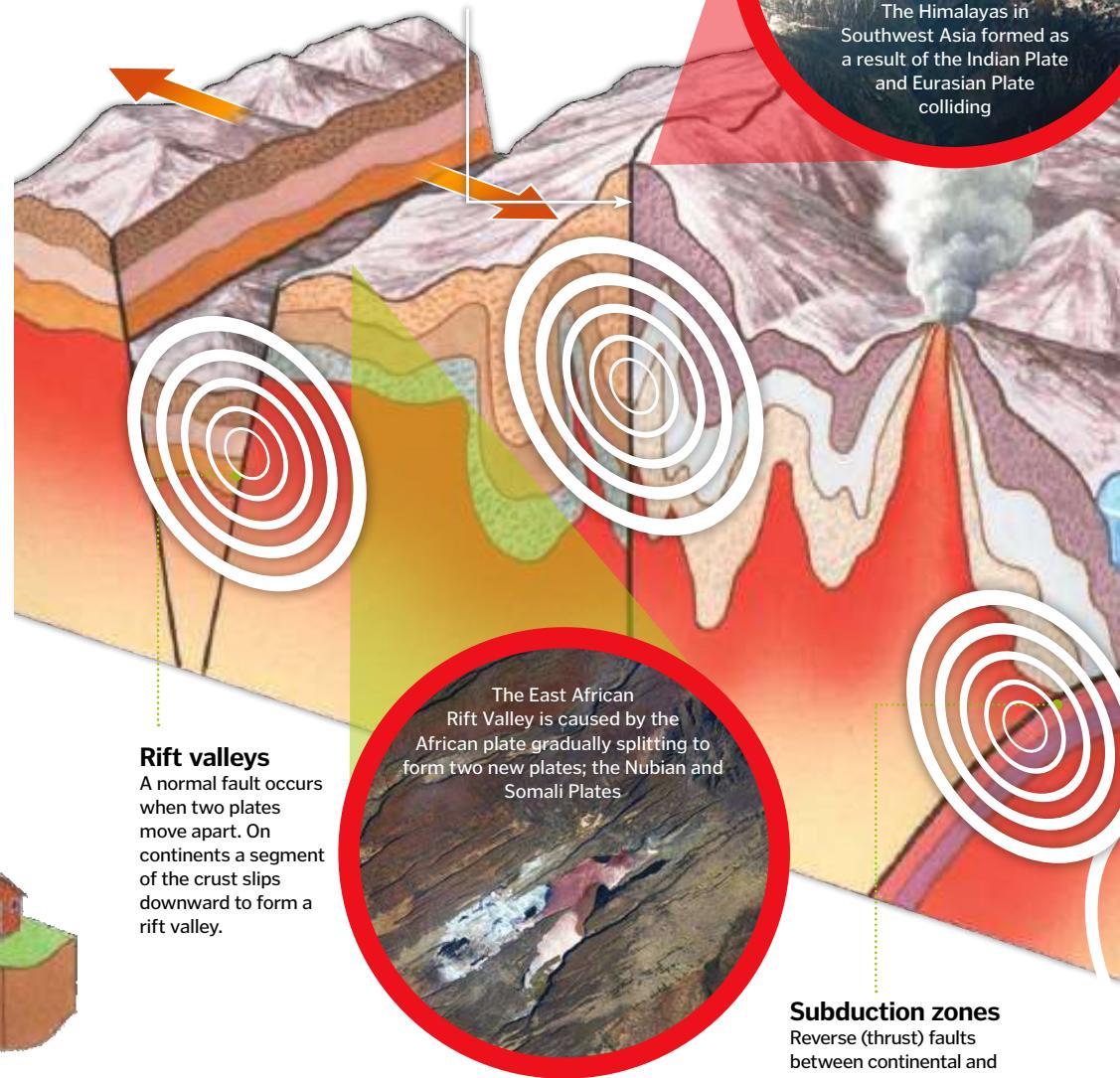
### The process starts again

Once the energy has been released, the plates will assume their new position and the process will begin all over again.



## Fault lines

How the Earth's crust moves along different plate boundaries

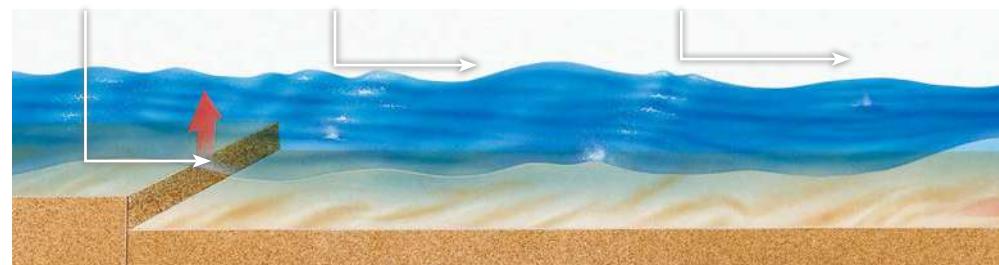


## Tsunamis

How underwater earthquakes trigger enormous and devastating waves

### Water displacement

As two oceanic plates slip past each other and cause an earthquake, a huge amount of water above it is displaced.



### Mountain formation

When two continental plates collide along a reverse (thrust) fault, the Earth's crust folds, pushing slabs of rock upward to form mountains.

The Himalayas in Southwest Asia formed as a result of the Indian Plate and Eurasian Plate colliding

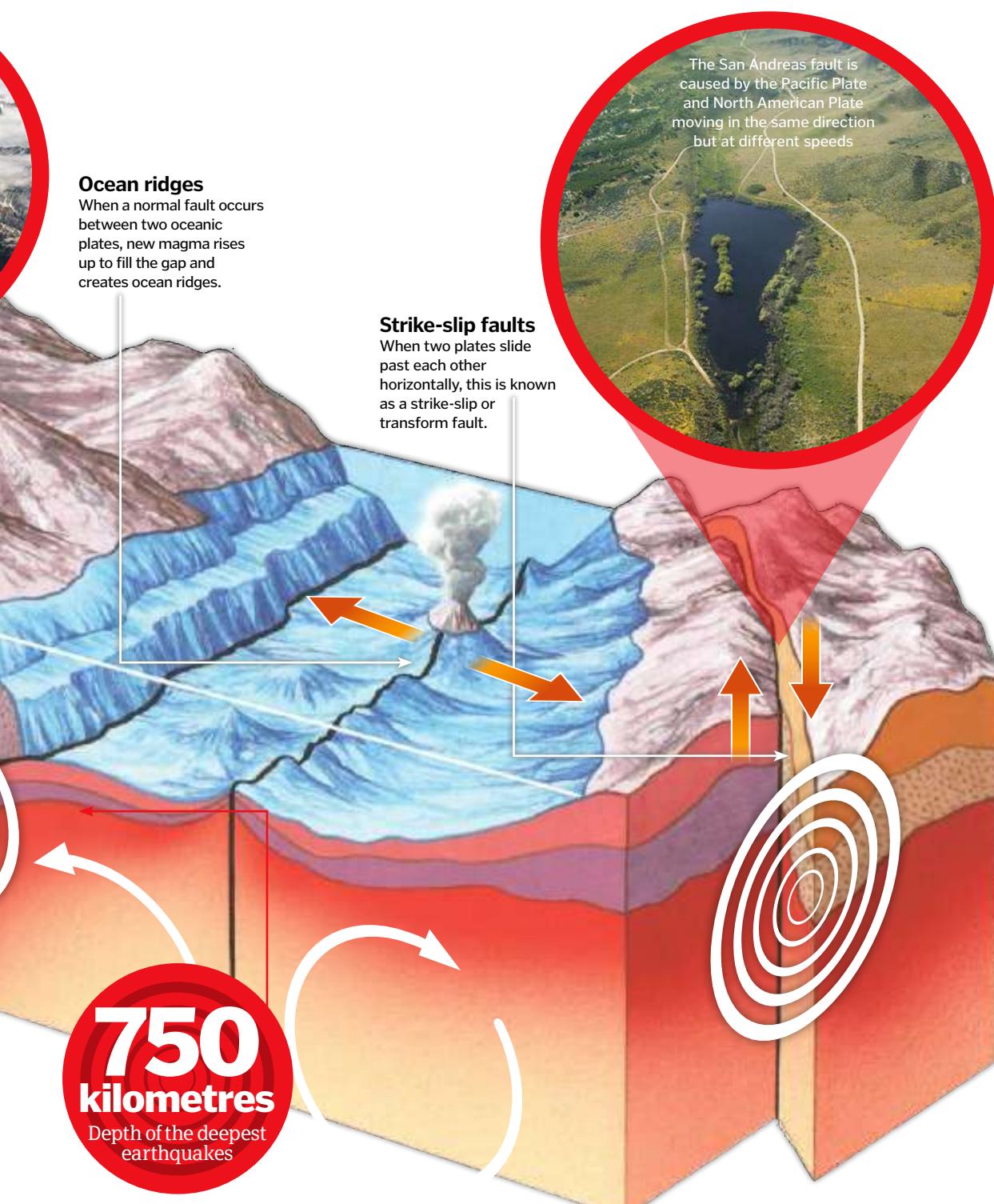
The East African Rift Valley is caused by the African plate gradually splitting to form two new plates; the Nubian and Somali Plates

### Subduction zones

Reverse (thrust) faults between continental and oceanic plates cause subduction, causing the higher-density oceanic plate to sink below the continental plate.

### Tsunami in disguise

The tsunami's long wavelength and small wave height – usually less than 1m (3.3ft) – means that it blends in with regular ocean waves.

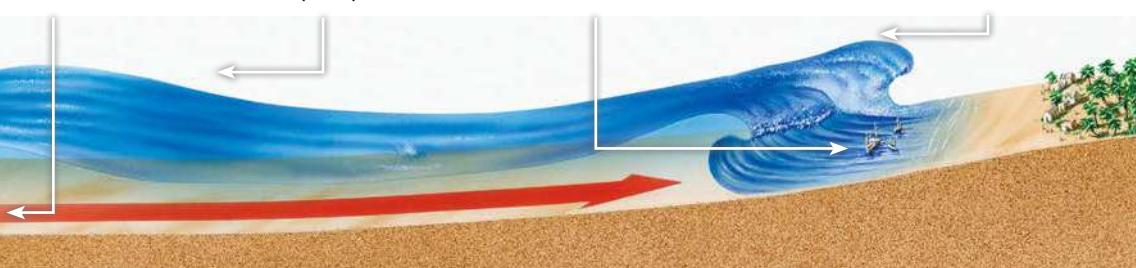


**Starting to slow**  
As they reach the shallower waters of the coast, the rising sea floor causes friction that slows the waves down.

**Waves begin to grow**  
As they slow down, the wavelengths begin to shorten, causing the tsunami to grow to a height of approximately 30m (100ft).

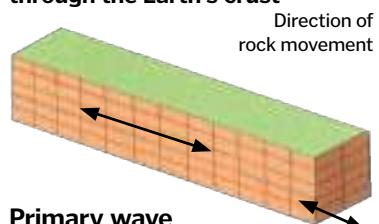
**Early warning**  
A tsunami's trough, the low point beneath the wave's crest, often reaches shore first, producing a vacuum effect that sucks coastal water seaward.

**The tsunami strikes**  
A few minutes later, the tsunami's crest will hit the shore followed by a series of more waves. This is known as a wave train.



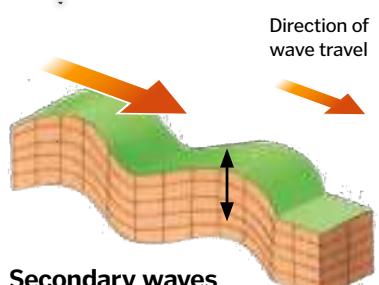
## Earthquake waves

How seismic waves travel through the Earth's crust



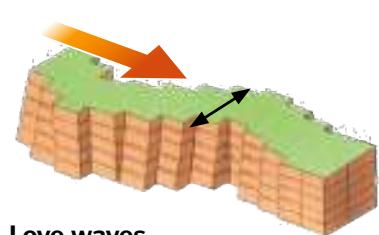
### Primary wave

P waves travel back and forth through the Earth's crust, moving the ground in line with the wave. They are the fastest moving of the waves, travelling at about 6-11km/s (3.7-6.8mi/s), and so typically arrive first with a sudden thud.



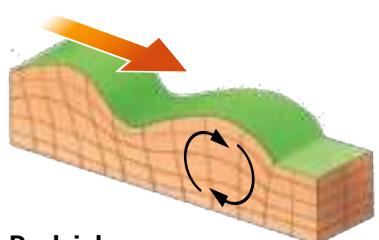
### Secondary waves

S waves move up and down, perpendicular to the direction of the wave, causing a rolling motion in the Earth's crust. They are slower than P waves, travelling at about 3.4-7.2km/s (2.1-4.5mi/s), and can only move through solid material, not liquid.



### Love waves

Unlike P and S waves, surface waves only move along the surface of the Earth and are much slower. Love waves, named after the British seismologist AEH Love, are the faster of the two types and shake the ground side to side, perpendicular to direction of the wave.



### Rayleigh waves

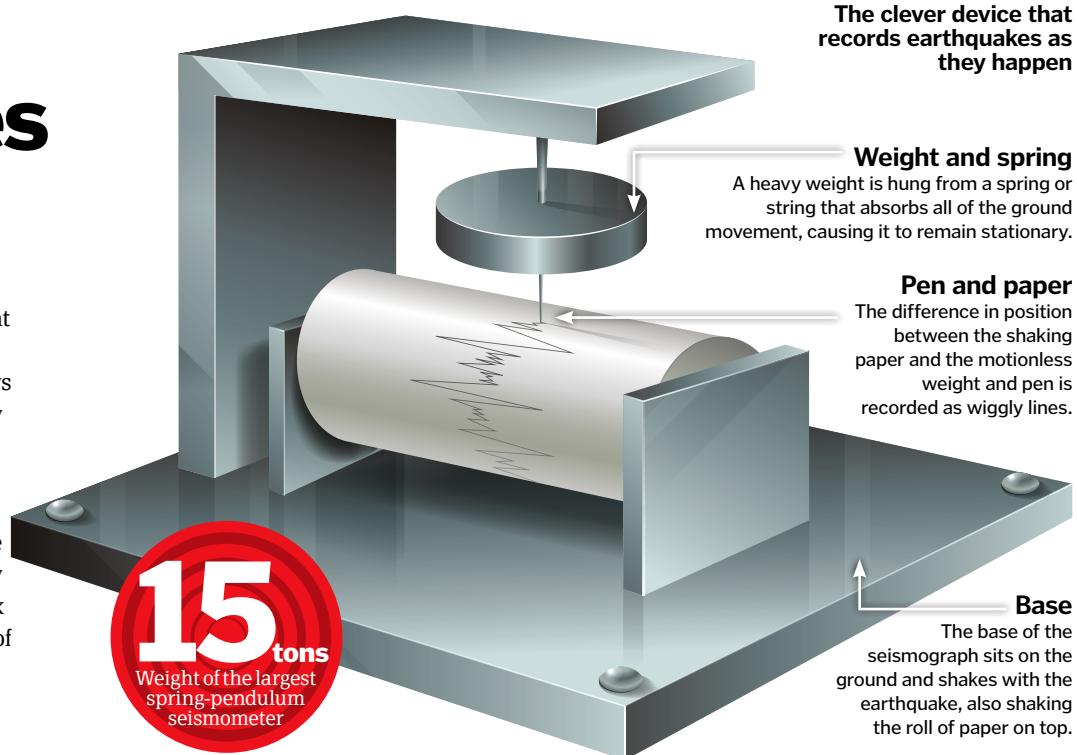
Rayleigh waves, named after the British physicist Lord Rayleigh, are surface waves that cause the ground to shake in an elliptical motion. Surface waves arrive last during an earthquake but often cause the most damage to infrastructure due to the intense shaking they cause.



# Monitoring earthquakes

Earthquake-recording methods of the past and present

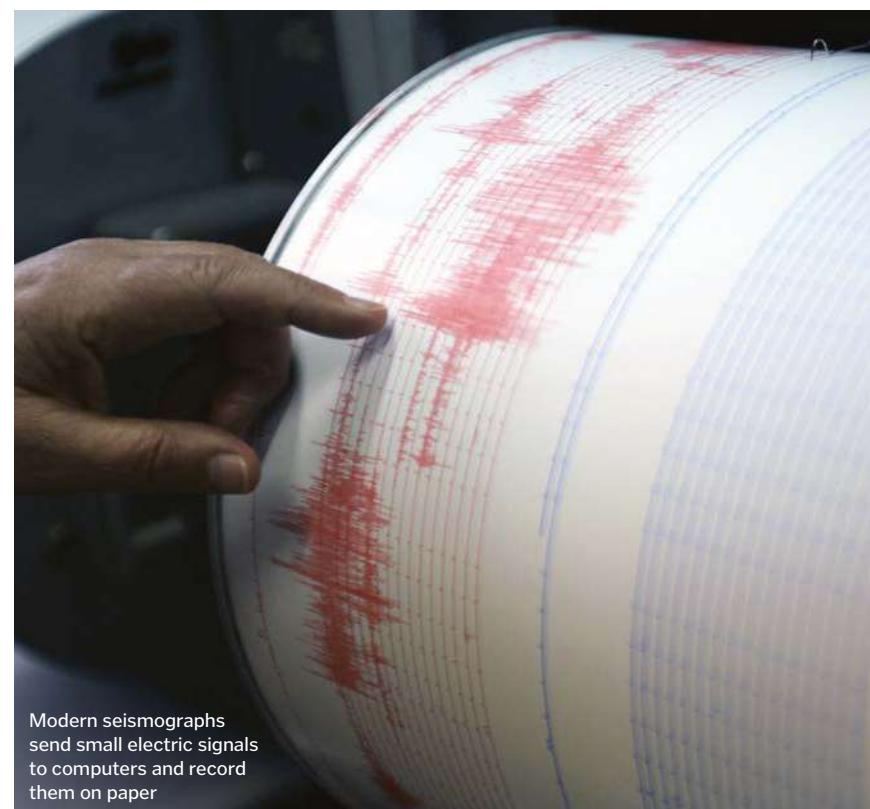
Earthquakes are measured using an instrument called a seismograph, which produces a visual record of tremors in the Earth's crust. This shows the seismic waves of the earthquake as a wiggly line, allowing you to plot the different waves types. The small but fast P waves appear first, followed by the larger but slower S waves and surface waves. The amount of time between the arrival of the P and S waves shows how far away the earthquake was, allowing scientists to work out the exact location of the epicentre. The size of the waves also helps them determine the magnitude or size of the earthquake, which is measured using the Richter Scale.



## The first seismograph

The earliest known seismoscope was invented by Chinese philosopher Chang Héng in 132. It didn't actually record ground movements, but simply indicated that an earthquake had hit. The cylindrical vessel had eight dragon heads around the top, facing the eight principal directions of the compass, each with an open-mouthed toad underneath it. Inside the mouth of each dragon was a ball that would drop into the mouth of the toad below

when an earthquake occurred. The direction of the shaking could be determined by which dragon released its ball. It is not known what was inside the vessel, but it is thought that some kind of pendulum was used to sense the earthquake and activate the ball in the dragon's mouth. The instrument reportedly detected a 650-kilometre (373-mile)-distant earthquake which was not felt by people at the location of the seismoscope.



## The Richter Scale

Measuring the magnitude of earthquakes using US seismologist Charles F Richter's system

**0-2.9**

There are more than 1 million micro earthquakes a year but they are not felt by people.

**3.0-3.9**

Minor earthquakes are felt by many people but cause no damage – there are as many as 100,000 of these a year.

**4.0-4.9**

Felt by all, light earthquakes occur up to 15,000 times a year and cause minor breakages.

**5.0-5.9**

A moderate earthquake causes some damage to weak structures. There are around 1,000 of them a year.





## Predicting earthquakes

### Modern methods that could help us plot future seismic activity

Currently, earthquakes cannot be predicted far enough in advance to give people much notice, but there are some early warning systems in place to give people a few seconds or minutes to prepare before the serious shaking starts. When seismometers detect the initial P waves, which don't usually cause much damage, they can estimate the epicentre and magnitude of the earthquake and alert the local population before the more destructive S waves arrive. Depending on their distance from the epicentre, people should then have just enough time to take cover, stop transport and shut down industrial systems in order to reduce the number of casualties.

Scientists are also enlisting the help of the general public to help them develop early warning systems. The Quake-Catcher Network (QCN) is a worldwide initiative supplying people with low-cost motion sensors that they can fasten to the floor in their home or workplace. These sensors are then connected to their computer and send real-time data about seismic activity to the QCN's servers, with the hope that earthquake

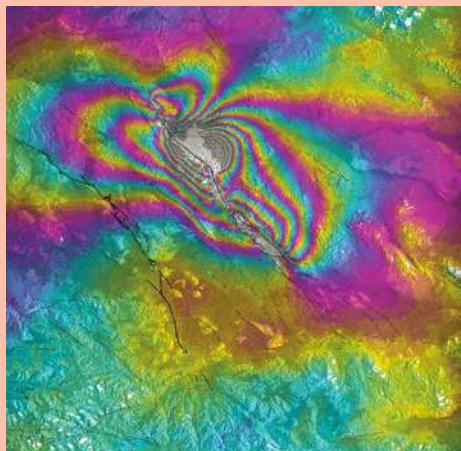
warnings can be issued when strong motions are detected in any of these.

To be able to predict earthquake further in advance, a characteristic pattern or change that precedes each earthquake needs to be identified. One suggestion is that increased levels of radon gas escape from the Earth's crust before a quake, however this can also occur without being followed by seismic activity, so does not provide conclusive evidence of a earthquake.

Scientists are even trying to determine whether animals can predict earthquakes better than we can, but no widespread unusual behaviour has been linked to earthquakes. Other potential earthquake-predicting methods are being tested in Parkfield, California along the San Andreas fault. Among other things, scientists are using lasers to detect the movement of the Earth's crust, sensors to monitor groundwater levels in wells, and a magnetometer to measure changes in the Earth's magnetic field, all with the hope that this will allow them to predict the next big quake.

### Radar mapping

One of the more recent developments in earthquake monitoring is interferometric synthetic aperture radar (InSAR). Satellites, or specially adapted planes, send and receive radar waves to gather information about the features of the Earth. The reflected radar signal of a fault line is recorded multiple times to produce radar images, which are then combined to produce a colourful interferogram (below). Each colour shows the amount of ground displacement that has occurred between the capturing of each image, mapping the slow warping of the ground surface that leads to earthquakes. This technique is sensitive enough to detect even tiny ground movements, allowing scientists to monitor fault lines in more detail and detect points where immense pressure is building up. It is hoped that this data will eventually enable scientists to tell when this pressure has reached a hazardous level, leading to more reliable earthquake predictions that give the public days or even weeks to prepare.



### 6.0-6.9

Over 100 strong earthquakes happen each year, causing moderate damage in populated areas.



### 7.0-7.9

A loss of life and serious damage over large areas are the result of major earthquakes that happen around ten times a year.



### 8.0 & higher

There are fewer than three earthquakes classed as 'great' each year, but they cause severe destruction and loss of life over large areas.



ON THE  
MAP10 major  
mountain ranges

## 1. Ural Mountains

TYPE: Fold mountain range in Russia and Kazakhstan

## 2. Altai Mountains

TYPE: Fault-block mountain range in Central Asia

## 3. Tian Shan

TYPE: Fault-block mountain range in Central Asia

## 4. Sumatra-Java range

TYPE: Discontinuous mountain range system containing active volcanoes, ranging the length of Sumatra (the Barisan Mountains) and Java

## 5. Serra do Mar

TYPE: Discontinuous mountain range system on east coast of Brazil, fault-block formation

6. Transantarctic  
Mountains

TYPE: Fault-block mountain chain that serves as a division between East and West Antarctica

## 7. Eastern Highlands

TYPE: Discontinuous fold mountain range system dominating eastern Australia

## 8. Himalayas

TYPE: Fold mountain range system in Asia between India and the Tibetan Plateau

## 9. Rocky Mountains

TYPE: Fold mountain range in western North America

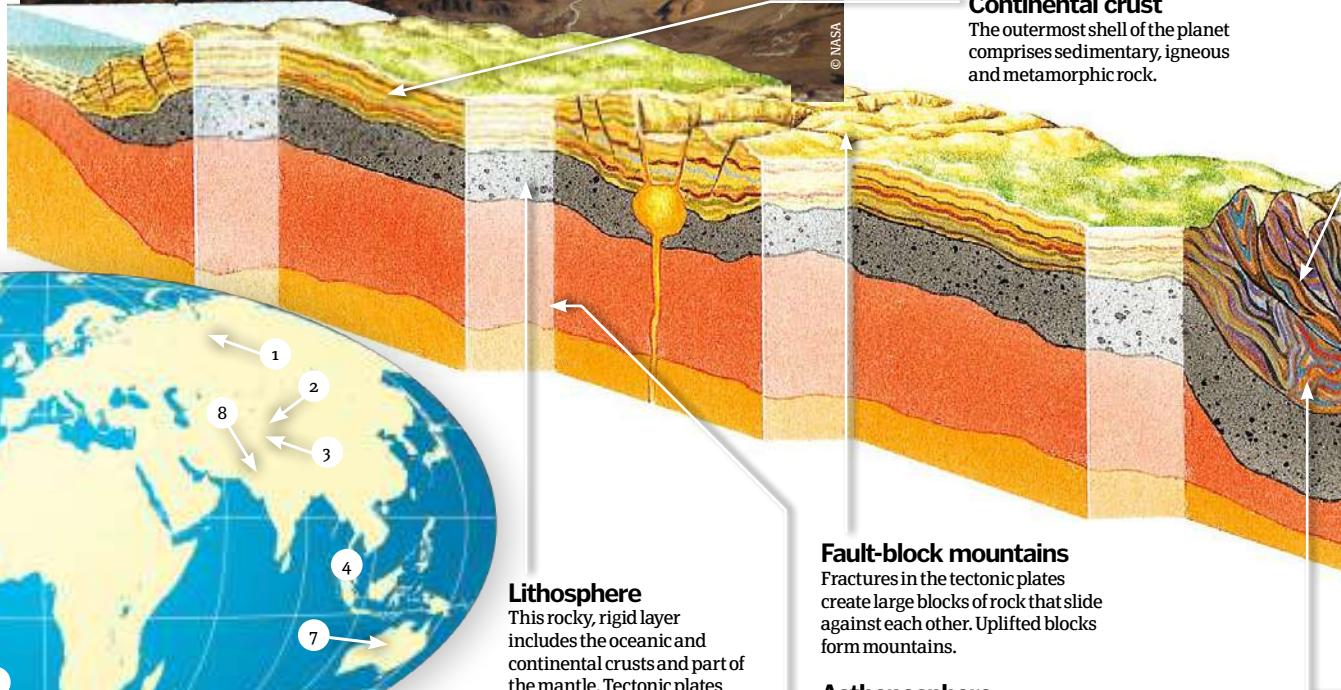
## 10. Andes

TYPE: Fold mountain range in South America



# Mountain formation

The Himalayas are home to the world's highest peaks



## Lithosphere

This rocky, rigid layer includes the oceanic and continental crusts and part of the mantle. Tectonic plates reside in this layer.

## How many ways can you make a mountain?

**M**ountains are massive landforms rising high above the Earth's surface, caused by one or more geological processes: plate tectonics, volcanic activity and/or erosion. Generally they fall into one of five categories – fold, fault-block, dome, volcanic and plateau – although there can be some overlap.

Mountains comprise about 25 per cent of our land mass, with Asia having more than 60 per cent of them. They are home to 12 per cent of the Earth's population, and they don't just provide beauty and recreation; more than half of the people

## Continental crust

The outermost shell of the planet comprises sedimentary, igneous and metamorphic rock.

## Fault-block mountains

Fractures in the tectonic plates create large blocks of rock that slide against each other. Uplifted blocks form mountains.

## Asthenosphere

This semiplastic region in the upper mantle comprises molten rock and it's the layer upon which tectonic plates slide around.

on Earth rely on the fresh water that flows down from the mountains to feed streams and rivers. Mountains are also incredibly biodiverse, with unique layers of ecosystems depending on their elevation and climate.

One of the most amazing things about mountains is that although they look solid and immovable to us, they're always changing and sometimes even growing. Mountains rising from activity associated with plate tectonics – fold and fault-block – form slowly over millions of years. The plates and rocks that initially interacted to form the mountains continue to move up to 2cm (0.8in) each year, meaning that the mountains grow. The Himalayas grow about 1cm (0.4in) per year.

The volcanic activity that builds mountains can wax and wane over time. Mount Fuji, the tallest mountain in Japan, has erupted 16 times since 781AD. Mount Pinatubo in the Philippines erupted in the early-Nineties without any prior recorded eruptions, producing the second largest volcanic eruption of the 20th century. Inactive volcanic mountains – and all other types of mountains, for that matter – are also subject to erosion, earthquakes and other activity that can dramatically alter their appearances as well as the landscape around us. There are even classifications for the different types of mountain peaks that have been affected by glacial periods in Earth's history. The bare, near-vertical mountaintop of the Matterhorn in the Alps, for example, is known as a pyramidal peak, or horn.

# Types of mountain



## Fold

This most common type of mountain is formed when two tectonic plates smash into each other. The edges buckle and crumble, giving rise to long mountain chains.

**Examples:** Mount Everest, Aconcagua



## Volcanic

These mountains are created by the buildup of lava, rock, ash and other volcanic matter during a magma eruption.

**Examples:** Mount Fuji, Mount Kilimanjaro



## Dome

These types of mountain also form from magma. Unlike with volcanoes, however, there is no eruption; the magma simply pushes up sedimentary layers of the Earth's crust and forms a round dome-shaped mountain.

**Examples:** Navajo Mountain, Ozark Dome



## Plateau

Plateau mountains are revealed through erosion of uplifted plateaux. This is known as dissection.

**Examples:** Catskill Mountains, Blue Mountains



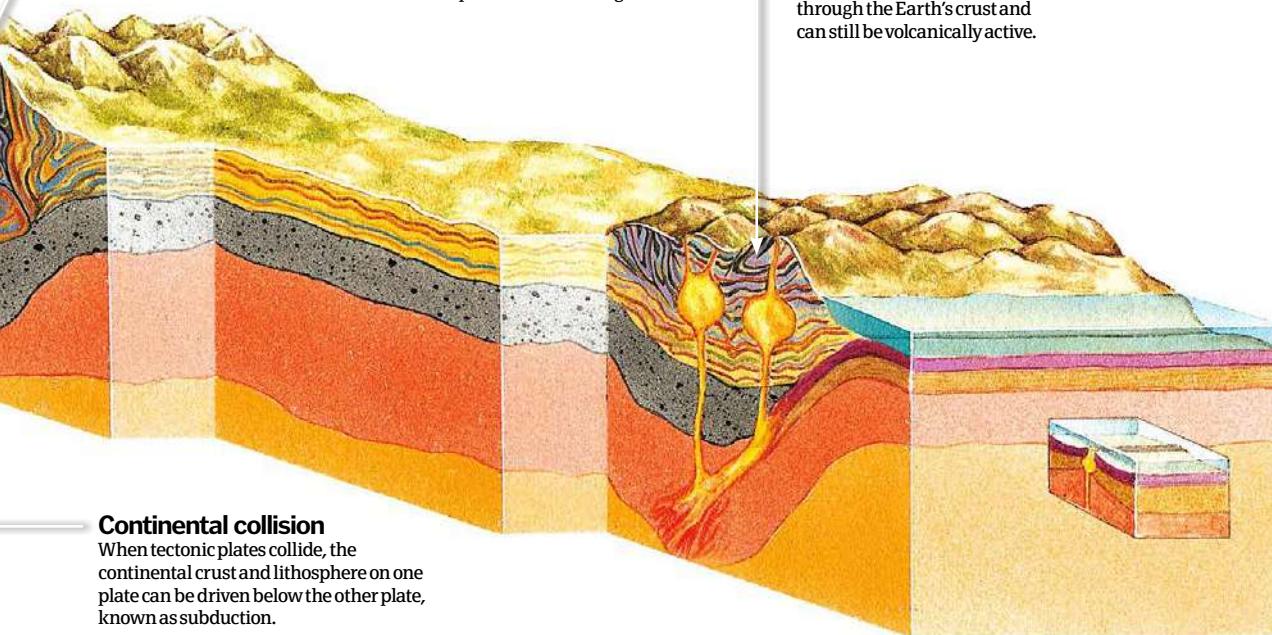
## Fault-block

Fault-block mountains form when cracked layers of crust slide against each other along faults in the Earth's crust. They can be lifted, with two steep sides; or lifted, with one gently sloping side and one steep side. **Examples:** Sierra Nevada, Urals

## Mountains made from below

### Fold mountains

Colliding plates experience crumpling and folding in the continental crust, forcing layers upwards and forming mountains.



### Continental collision

When tectonic plates collide, the continental crust and lithosphere on one plate can be driven below the other plate, known as subduction.

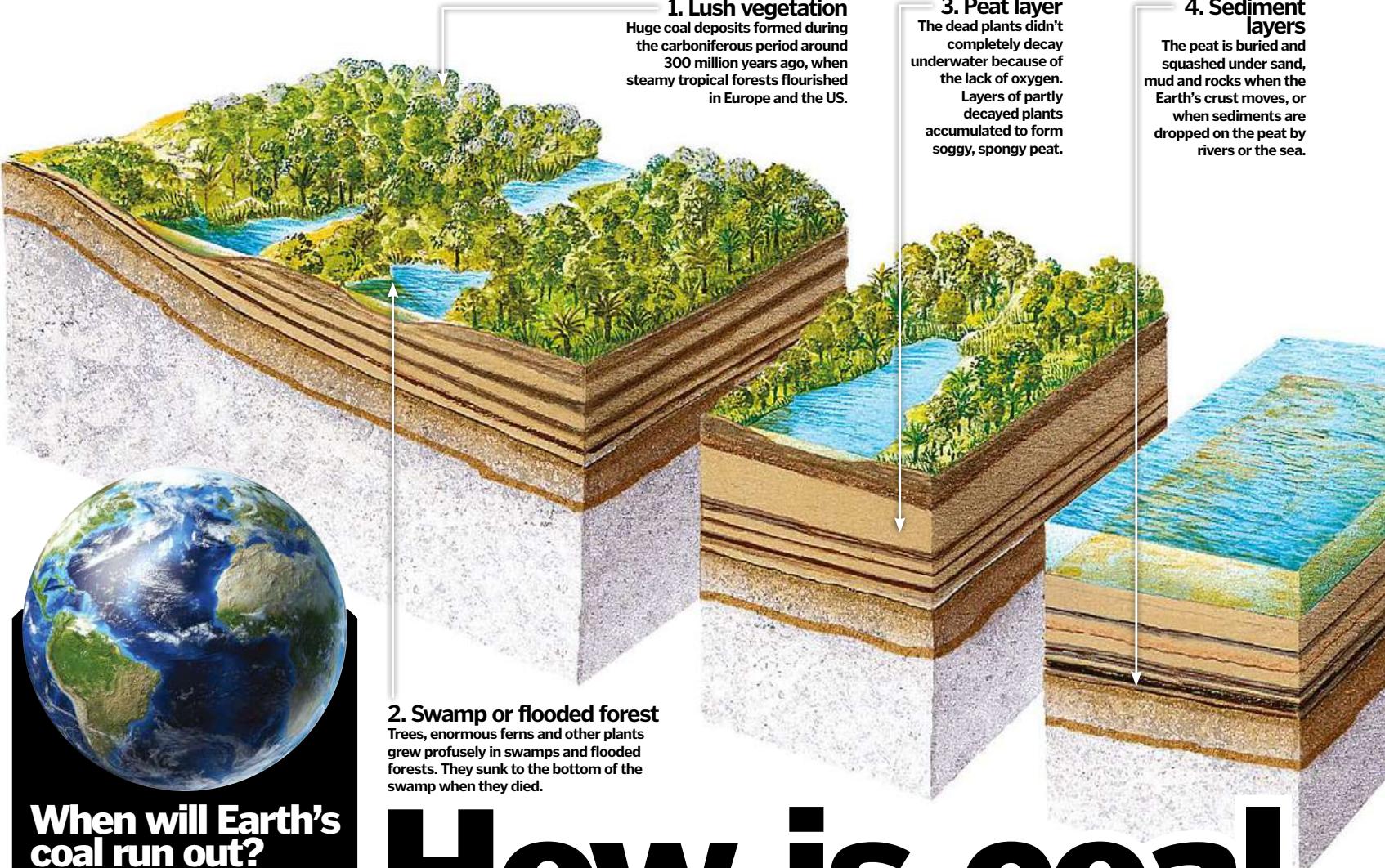
### Volcanic mountains

These mountains form when molten rock explodes up through the Earth's crust and can still be volcanically active.

Mountains are home to 12 per cent of the world's population



© NASA



## When will Earth's coal run out?

No one knows exactly when we'll run out of coal, but its use has skyrocketed during the last 200 years. We used a whopping 6.8 billion tons – that's the approximate weight of 4 billion cars – in 2009 alone. Around 860 billion tons of coal remains unmined and major coal producers estimate supplies will last around 130 years at current rates.

Despite this estimate we can't be sure that coal won't run out sooner, as the world's remaining coal may turn out to be hard to reach or bad quality. Worse still, we're uncertain how much coal is buried. India, for example, overestimated its coal reserves by 36 billion tons in 2003. Alternatively, we may develop better sources of energy, stop using coal and never run out.



# How is coal formed?

## Discover how your laptop is powered by plants that died before the dinosaurs

**E**ssential to modern life, around 40 per cent of the world's electricity comes from burning coal. The substance is used to make liquid fuel, plastics, concrete and even items such as head lice shampoo.

You might expect coal to be a high-tech material, because it has many sophisticated applications. But coal is simply a rock made from fossilised plants that died in swamps up to 100 million years before the first dinosaurs. Prehistoric plants captured energy from the Sun during their lives and locked it up as carbon in coal. We burn coal in power stations to release this ancient solar energy. This is why coal is sometimes called 'buried sunshine'.

Coal is mainly carbon and water. Carbon-rich coals contain little water and release lots of energy when

burned. Low-carbon coals spent less time buried underground and contain more water and impurities. Coal 'rank' or quality depends on water and carbon content. There are four ranks: lignite, sub-bituminous, bituminous and anthracite. Up to ten per cent of a coal's weight comprises of sulphur. Modern power stations stop sulphur reaching the atmosphere.

All the fossil fuels we burn – coal, oil and gas – are the carbon-rich remains of prehistoric organisms. We describe fossil fuels as 'non-renewable' because these ancient stores of energy take millions of years to replenish once used. Rapidly releasing carbon from storage also pollutes the atmosphere. A byproduct of burning coal is carbon dioxide gas, a major cause of global warming.

# Coal formation

## 5. Lignite

The peat is crushed and water is squeezed out by the weight of overlying sediments. Eventually, heat and pressure underground turns the peat into a soft, brown coal called lignite.



The plants that formed coal died long before dinosaurs roamed the Earth



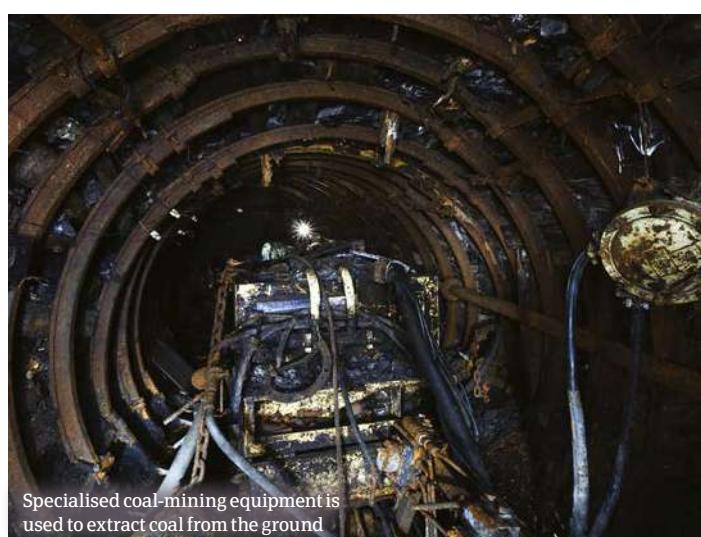
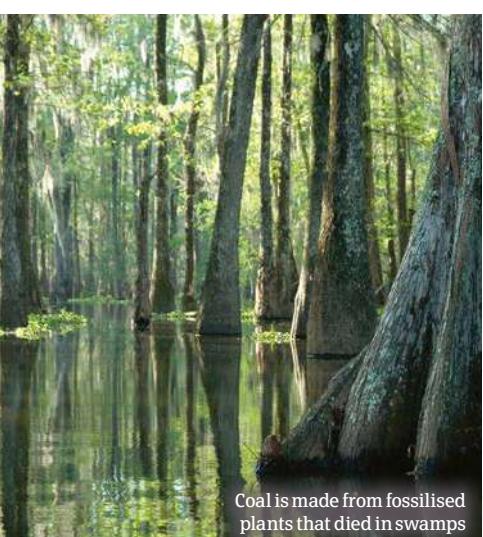
## 6. Bituminous and anthracite coal

Continued heat and pressure turn lignite into soft, black bituminous coal and hard, lustrous anthracite. These coals are richer in carbon than lignite because impurities and water are squeezed out.



## 7. Open-pit coal mine

Millions of years after plants died in the swamp, humans dig coal from the ground. Coal is dug from an open pit when it's found near the surface.



© Thinkstock

Wind turbines produce electricity



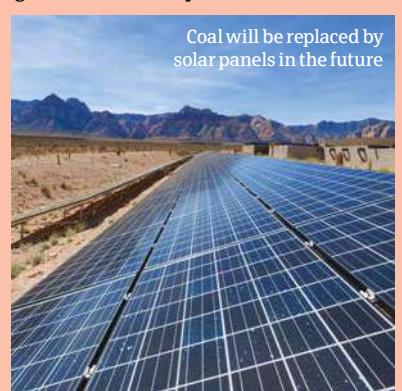
## Energy for the future

We can't power our civilisation with ancient plants forever. In the future, we'll harness energy sources that don't run out in human lifetimes. An example is capturing the Sun's vast energy with light-gathering solar panels. Covering one per cent of the Sahara Desert with panels could generate enough energy to power the world.

Solar energy fuels the Earth's water cycle, which keeps rivers rushing downhill. This fast-moving water can spin propellers and generate electricity. Tide and bobbing wave movements can also drive electricity generators. Movements of the Moon, Sun and Earth cause tides and won't stop anytime soon.

Wind turbines are a familiar sight on breezy hills and huge turbine farms can also be built out at sea. The wind spins the turbine blades to generate electricity. Another energy source is the Earth's core, which is as hot as the Sun's surface. This heat can warm homes or generate electricity.

Coal will be replaced by solar panels in the future



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# What are fossils?

Obliterating the traditional perception of the origins and evolution of life on Earth, fossils grant us unique snapshots of what once lived on our ever-changing planet



### Adpression

A form of fossilisation caused by compression within sedimentary rock. This type of fossilisation occurs mainly where fine sediment is deposited frequently, such as along rivers. Many fossilised plants are formed this way.

### Resin

Referred to as amber, fossil resin is a natural polymer excreted by trees and plants. As it is sticky and soft when produced, small invertebrates such as insects and spiders are often trapped and sealed within resin, preserving their form.

### Bioimmuration

Bioimmuration is a type of fossil that in its formation subsumes another organism, leaving an impression of it within the fossil. This type of fossilisation usually occurs between sessile skeletal organisms, such as oysters.

## Types of fossilisation

Dependent on climate and ground conditions, deceased animals can be fossilised in many ways

### Recrystallisation

When a shelled creature's shell, bone or tissue maintains its original form but is replaced with a crystal – such as aragonite and calcite – then it is said to be recrystallised.

### Mold

A type of fossilisation process similar to permineralisation, molds occur when an animal is completely dissolved or destroyed, leaving only an organism-shaped hole in the rock. Molds can turn into casts if they are then filled with minerals.

### Permineralisation

A process in which mineral deposits form internal casts of organisms, permineralisation works when an animal dies and then is rapidly submerged with groundwater. The water fills the creature's lungs and empty spaces, before draining away leaving a mineral cast.

**T**he origin of life on Earth is irrevocably trapped in deep time. The epic, fluid and countless beginnings, evolutions and extinctions are immeasurable to humankind; our chronology is fractured, the picture is incomplete. For while the diversity of life on Earth today is awe-inspiring, with animals living within the most extreme environments imaginable – environments we as humans brave every day in an effort to chart and understand where life begins and ends – it is but only a fraction of the total life Earth has seen inhabit it over geological time. Driven by the harsh realities of an ever-changing

environment, Armageddon-level extinction events and the perpetual, ever-present force of natural selection, wondrous creatures with five eyes, fierce predators with foot-long fangs and massive creatures twice the size of a double-decker bus have long since ceased to exist. They're forgotten, buried by millions of years. Still, all is not lost. By exploiting Earth's natural processes and modern technology, scientists and palaeontologists have begun to unravel Earth's tree of life and, through the discovery and excavation of fossils – preserved remains and traces of past life in Earth's crust – piece the jigsaw back together.

## Carbon dating

A crucial tool for palaeontologists, carbon dating allows ancient fossils to be accurately dated

Carbon dating is a method of radioactive dating used by palaeontologists that utilises the radioactive isotope carbon-14 to determine the time since it died and was fossilised. When an organism dies it stops replacing carbon-14, which is present in every carbonaceous organism on Earth, leaving the existing carbon-14 to decay. Carbon-14 has a half-life (the time it takes a decaying object to decrease in radioactivity by 50 per cent) of 5,730 years, so by measuring the decayed levels of carbon-14 in a fossil, its time of death can be extrapolated and its geological age determined.



This scientist is dating archaeological specimens in a Tandetron particle accelerator

© Science Photo Library

The fossilisation of an animal can occur in a variety of ways (see 'Types of fossilisation' boxout) but, in general, it occurs when a recently deceased creature is rapidly buried by sediment or subsumed in an oxygen-deficient liquid. This has the effect of preserving parts of the creature – usually the harder, solid parts like its skeleton – often in the original, living form within the Earth's crust. The softer parts of fossilised creatures tend not to survive due to the speed of decay and their replacement by minerals contained in their sediment or liquid casing, a process that can leave casings and impressions of the animal that once lived, but not its remains. Importantly, however, creature fossilisation tends to



be specific to the environmental conditions in which it lived – and these in themselves are indicative of certain time periods in Earth's geological history. For example, certain species of trilobite are only found in certain rock strata, which itself is identifiable by its materials and mineralogic composition. This allows palaeontologists to extrapolate the environmental conditions (hot, cold, dry, wet, etc) that the animal lived and died in and, in partnership with radiometric dating, assign a date to the fossil.

Interestingly, however, by studying the strata and the contained fossils over multiple layers, through a mixture of this form of palaeontology and phylogenetics (the study of evolutionary relationships between organism groups), scientists can chart the evolution of animals over geological time scales. A good example of this process is the now known transition of certain species of dinosaur into birds. Here, by dating and analysing specimens such as *Archaeopteryx* – a famous dinosaur/bird transition fossil – both by strata and by radiometric methods, as well as recording their molecular and morphological data, scientists can then chart its progress through strata layers to the present day. In addition, by following the fossil record in this way, palaeontologists can also attribute the geophysical/chemical changes to the rise, fall or transition of any one animal/plant group, reading the sediment's composition and structural data. For example, the Cretaceous-Tertiary extinction event is identified in sedimentary strata by a sharp decline in species' diversity – notably non-avian dinosaurs – and increased calcium deposits from dead plants and plankton.

Excavating any discovered fossil in order to date and analyse it is a challenging, time-consuming process, which requires special tools and equipment. These include picks and shovels, trowels, whisks, hammers, dental drills and even explosives. There is also an accepted academic method all professional palaeontologists follow when preparing, removing and transporting any discovered fossil. First, the fossil is partially freed from the sedimentary matrix it is encased in and labelled, photographed and reported. Next, the overlying rock is removed using large tools up to a distance of 5-7.5 centimetres (two to three inches) from the fossil, before it is once again photographed. Then, depending on the stability of the fossil, it is coated with a thin glue via brush or aerosol in order to strengthen its structure, before being wrapped in a series of paper, bubble wrap and Hessian cloth. Finally, it is transported to the laboratory.



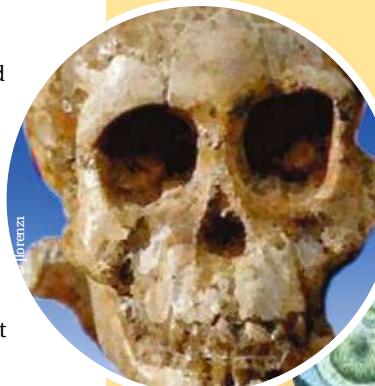
# THE FOSSIL RECORD

By examining discovered fossils, it is possible to piece together a rough history of the development of life on Earth over a geological timescale



## 12 | CAMBRIAN | 542-488.3 Ma

The first geological period of the Paleozoic era, the Cambrian is unique in its high proportion of sedimentary layers and, consequently, adpression fossils. The Burgess Shale Formation, a notable fossil field dating from the Cambrian, has revealed many fossils including the genus *opabinia*, a five-eyed ocean crawler.



## 11 | ORDOVICIAN | 488.3-443.7 Ma

Boasting the highest sea levels on the Palaeozoic era, the Ordovician saw the proliferation of planktonics, brachiopods and cephalopods. Nautiloids, suspension feeders, are among the largest creatures from this period to be discovered.



## 9 | DEVONIAN | 416-359.2 Ma

An incredibly important time for the development of life, the Devonian period has relinquished fossils demonstrating the evolution of the pectoral and pelvic fins of fish into legs. The first land-based creatures, tetrapods and arthropods, become entrenched and seed-bearing plants spread across dry lands. A notable find is the genus  *tiktaalik*.

## 10 | SILURIAN | 443.7-416 Ma

With its base set at major extinction event at the end of the Ordovician, the silurian fossils found differ markedly from those that pre-date the period. Notable life developments include the first bony fish, and organisms with moveable jaws.







# AMAZING ANIMALS

## Corals

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**106 The animal kingdom**

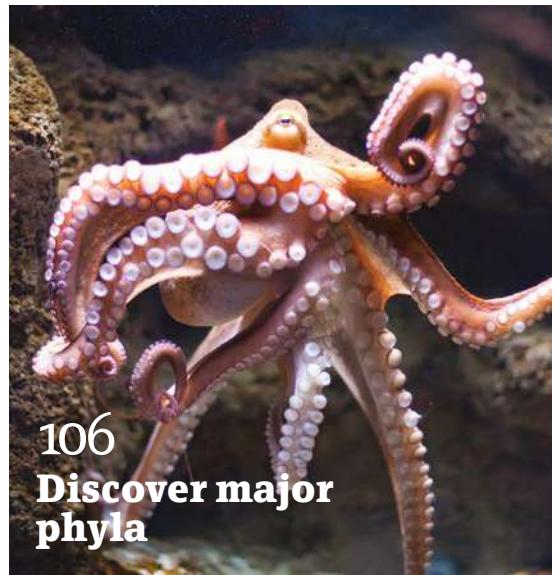
Discover the animal tree of life, and how all living things co-exist in harmony

**114 Big cat attack**

These predators are far removed from your furry household pet, and will do anything for a meal

**122 Glow-in-the-dark animals**

Adjust your eyes to a multicolour world of natural light



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Discover major phyla

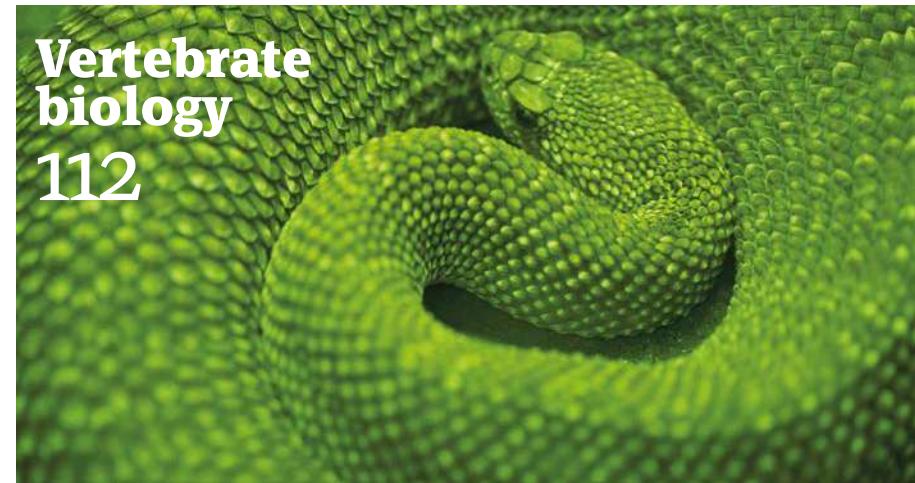
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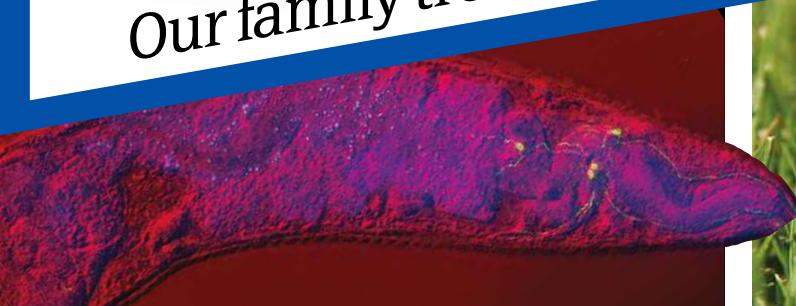
Invertebrate anatomy





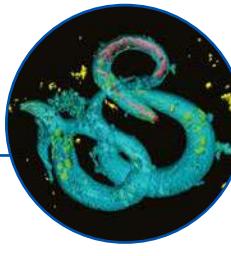
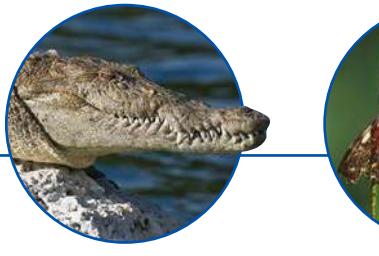
# THE ANIMAL KINGDOM

Our family tree is a lot stranger than you might first think



## Major phyla

The animal kingdom has approximately 35 phyla. Discover nine of the main ones now...



### Chordata

Animals with a notochord (primitive backbone). Vertebrates are chordates but they only have a notochord as embryos. After that it develops into a true spine.

### Arthropoda

A hard exoskeleton with jointed legs and a body divided into segments. It is the most diverse phylum, with well over a million known species on Earth.

### Mollusca

Molluscs have a mantle cavity for breathing, which is often protected by a shell. But the shell can be spiral, hinged or missing altogether – eg cephalopods.

### Nematoda

Thread-like worms ranging from microscopic to several metres in length. They have a distinct head, with teeth or a stabbing syringe, and a simple intestine.



## Sort your life out!

A brief guide to how we structure all life on Earth

**Domain**

**Kingdom**

**Phylum**

**Class**

**Order**

**Family**

**Genus**

**Species**

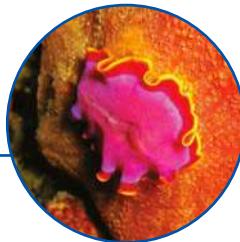
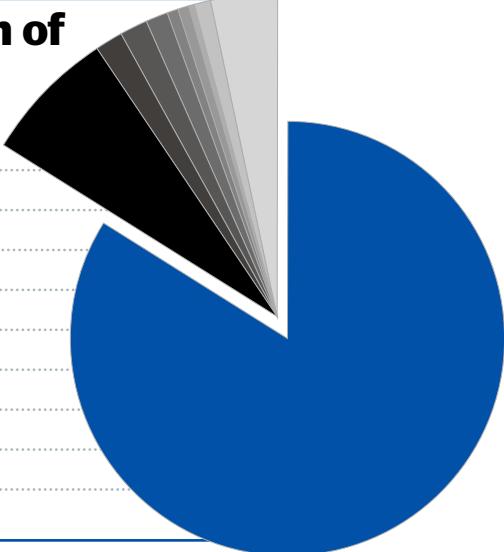
In the fourth century BCE, Aristotle divided the world into animals and plants. The word 'animal' comes from the Latin *animalis* and means 'having breath'. Animals were all the living creatures that moved and breathed, while plants were the ones that stayed put. For over 2,000 years the living world was divided into just these two kingdoms. After the invention of the microscope and later the electron microscope, scientists came to recognise that single-celled organisms couldn't really be classified as animals *or* plants. Bacteria and another type of single-celled organism called Archaea are now counted as fundamentally different groups of their own. That leaves animals, plants and fungi as fairly recent evolutionary offshoots from the larger group of organisms with a cell nucleus, called the eukaryotes.

The animal kingdom consists of the eukaryotes that are multicellular. Their cells are specialised into different types and grouped into tissues that perform different functions. Animals are divided into major groups, known as phyla, and each phylum has animals with a radically different arrangement of these tissues. All animals obtain their energy by eating other organisms, so they need some

way of catching and digesting these organisms. But there are a lot of ways of solving this problem. So, for example, the echinoderms, which include starfish, are all radially symmetrical, while the arthropods all have rigid, jointed exoskeletons. There are nine main phyla, with a couple of dozen much smaller ones containing all the odd and difficult to classify creatures. Indeed, between them,

### What proportion of species belongs to each group?

■ Arthropoda: 83.7%
■ Mollusca: 6.8%
■ Chordata: 3.6%
■ Nematoda: 1.4%
■ Platyhelminthes: 1.4%
■ Annelida: 1.0%
■ Cnidaria: 0.6%
■ Echinodermata: 0.5%
■ Porifera: 0.3%
■ Others: 0.7%



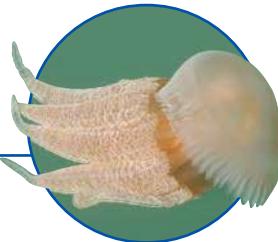
#### Platyhelminthes

Very simple flatworms with no specialised circulation or respiratory system. The digestive cavity has a single opening serving as both mouth and anus.



#### Annelida

Roundworms with bodies built from repeating segments. Each segment has the same internal organs and may have bristles or appendages to help them move.



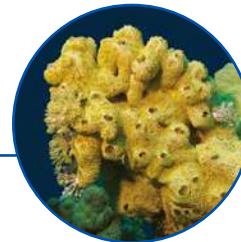
#### Cnidaria

A body formed from two layers of cells sandwiching a layer of jelly in between. The outer layer has specialised stinging cells (cnidocytes) for catching prey.



#### Echinodermata

Unusual because of their radial symmetry – usually fivefold but occasionally seven or more. Their skin is covered with armoured plates or spines.



#### Porifera

Very simple animals with no nervous, digestive or circulatory systems. Instead, nutrients and waste are carried through their porous bodies by water currents.



these nine groups account for more than 99 per cent of all animal species alive today.

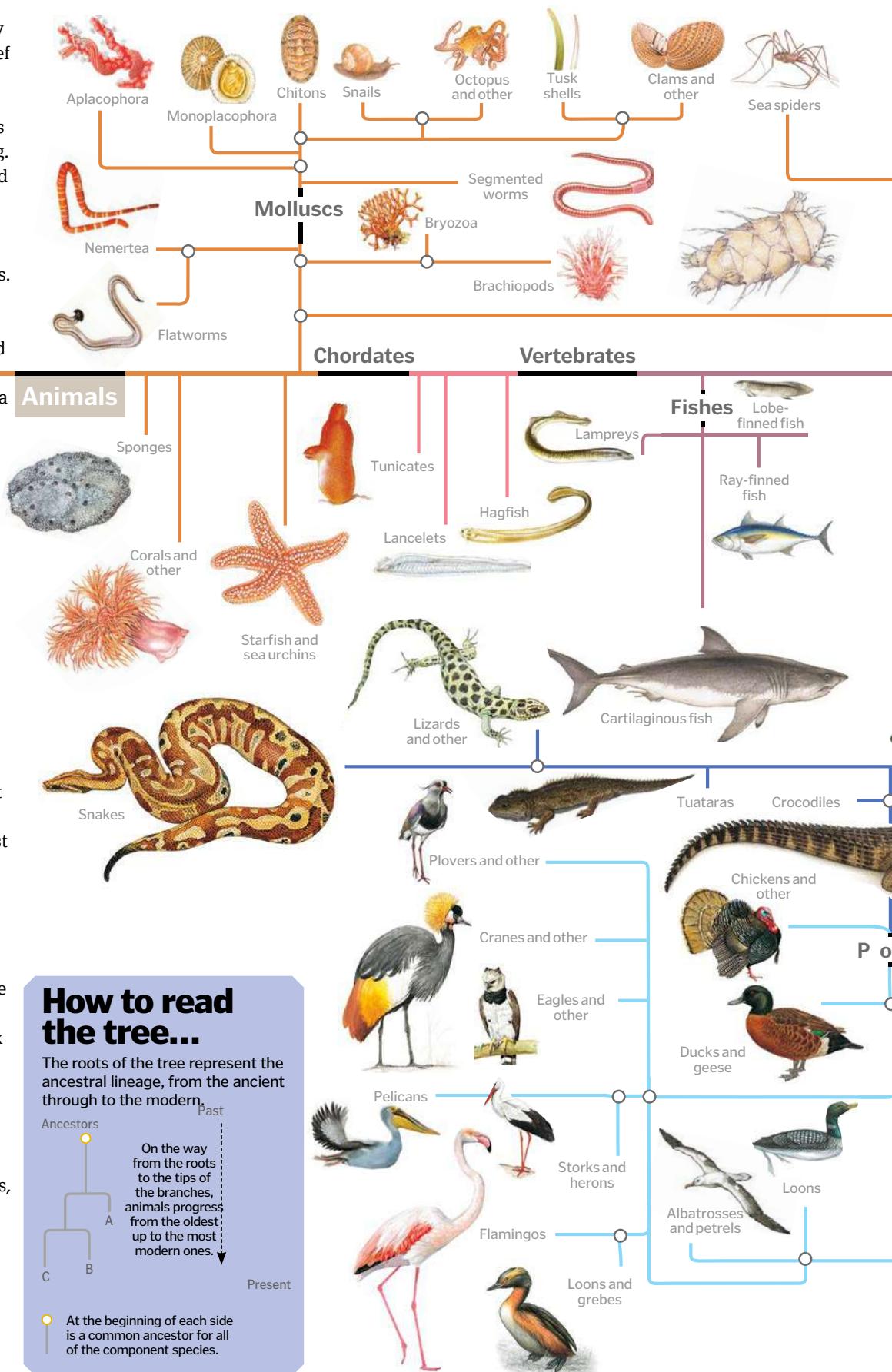
At a first glance, some of the groups seem very similar. The annelids are segmented worms, while the nematodes are roundworms and the platyhelminths are flatworms. Why aren't they all just grouped together as worms? Even a brief look at their internal structure shows the reason. Flatworms have bodies that are left/right symmetrical and their digestive system is just a simple sack shape with only one opening. Roundworms have a radially symmetrical head and a tubular digestive system that has an opening at each end. Annelids are even more sophisticated internally, with bodies made of repeating segments and distinct organ systems. The characteristics that separate these three groups of animals are far more important than the things that link them together. Being called a 'worm' just means that your body is long and thin with no legs, after all. That also applies to a snake, and snakes clearly aren't worms.

Snakes are vertebrates, of course, but surprisingly, the vertebrates aren't considered a phylum of their own. Instead they are grouped within the chordates. That's because the backbone itself isn't the most important distinguishing feature; rather it's the nerve cord running the length of the body that the backbone protects. There are some simple fish-like creatures that have a spinal cord even though they don't have bony vertebrae. The spinal cord was the adaptation that led to the development of our complex nervous systems, and it is such an important feature that all creatures with a spinal cord are grouped together in the chordates. However, 97 per cent of all animals are still invertebrates. The vertebrate animals – which include us – are just a subgroup of a single phylum.

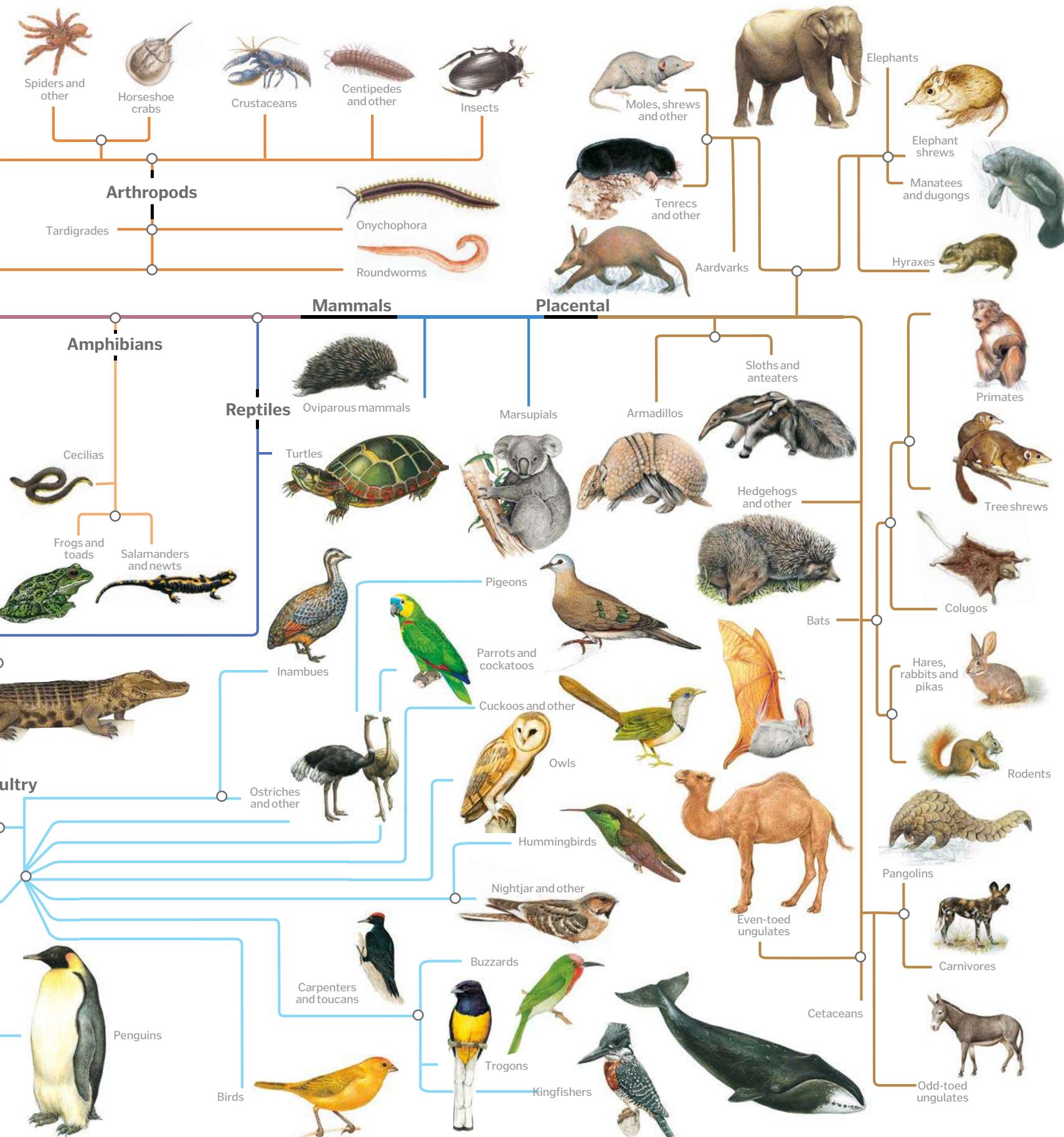
So which is the largest of the groups then? It depends on how you count it. In terms of the sheer number of individuals, the nematodes are the most numerous. But they are also very small, so it's not an entirely fair measure. There are over a million nematodes in every square metre of soil! Biologists generally prefer to look at the number of different species in a group. This is a way of measuring how successful a particular body plan has been in adapting to different environments. By that measure, the arthropods are currently in the lead – around 84 per cent of all known species are arthropods,

**"Our system of naming animals was devised by Carl Linnaeus"**

## The animal tree of life



**DID YOU KNOW?** The extinct Moa bird wasn't just flightless; it actually had no wings. All living birds at least have vestigial wings.





mostly in the subgroup of insects. But this is also a somewhat misleading statistic. There are a lot of species still waiting to be discovered and identified. Insects are easy to catch, preserve well and most of their distinguishing characteristics can be seen with nothing more sophisticated than a magnifying glass.

Nematodes, on the other hand, are mostly microscopic and, although tens of thousands of species have been described so far, they all look very similar. It's possible that there are as many as a million more species of nematode out there waiting to be discovered and named. If so, this would make them roughly level with the arthropods in species numbers.

The system of naming animals that we use today was devised by the Swedish naturalist Carl Linnaeus (or Carl von Linné as he was known after he was made a noble). He used a two-part name to uniquely identify every animal and plant. It consists of a genus and a species, like a surname and a first name, except that it is written with the genus first and then the species. So the chimpanzee belongs to the genus *Pan* and the species *troglodytes*. The name is often written in italics with the genus capitalised: *Pan troglodytes*. The bonobo chimp, meanwhile, belongs to the same genus but has a different species: *Pan paniscus*.

Above the level of genus, animals are grouped together into families, then orders, then classes, then phyla. So, for example, the dromedary camel belongs to the kingdom of animals, the phylum of chordates, the class of mammals, the order Artiodactyla, the family Camelidae, the genus *Camelus* and the species *dromedarius*. The higher groupings are used to show the evolutionary relationships between animals, but *Camelus dromedarius* is all you need to precisely identify which organism you are talking about, from the entirety of the natural world. The genus name is often abbreviated, particularly when it is long. So the bacterium *E. coli* is actually *Escherichia coli*.

In general, the division of the animal kingdom into groups reflects how closely related the animals in that group are to each other, but there are exceptions. Birds are actually more closely related to crocodiles than snakes are, and yet both crocodiles and snakes are in the class of reptiles, and birds have their own class: Aves. This is because birds all have lots of physical resemblances to each other that make them feel like a coherent group, whereas reptiles are actually a grab-bag class with only superficial physical resemblances. The reptiles are really just the leftover vertebrates that aren't birds, mammals or amphibians.

Species though are a much more fundamental unit of classification. Animals in

## Invertebrate anatomy

United by their lack of backbone, what are invertebrates really like?

### INSECTS

**Phylum:** Arthropoda

**Phylum also includes:**

Spiders, scorpions, centipedes, millipedes, crustaceans

**Info:** Insects are the most diverse group of animals on Earth. It's possible that 90 per cent of all species are insects. They have three body segments, with three pairs of legs and one or two pairs of wings on the middle segment. The whole body is protected by a waterproof, rigid exoskeleton that also provides an attachment point for the muscles. Insects have a larval form that is often aquatic but very few insects live in saltwater.

### SPONGES

**Phylum:** Porifera

**Phylum also includes:** Calcareous sponges, glass sponges

**Info:** Most sponges belong to the class Demospongiae. Although a sponge has different cell types, the body structure is very loosely organised. Amazingly if you pass a sponge through a sieve to separate the cells, they will reform into sponges. Most sponges photosynthesise using symbiotic bacteria, though a few prey on plankton and even shrimp.

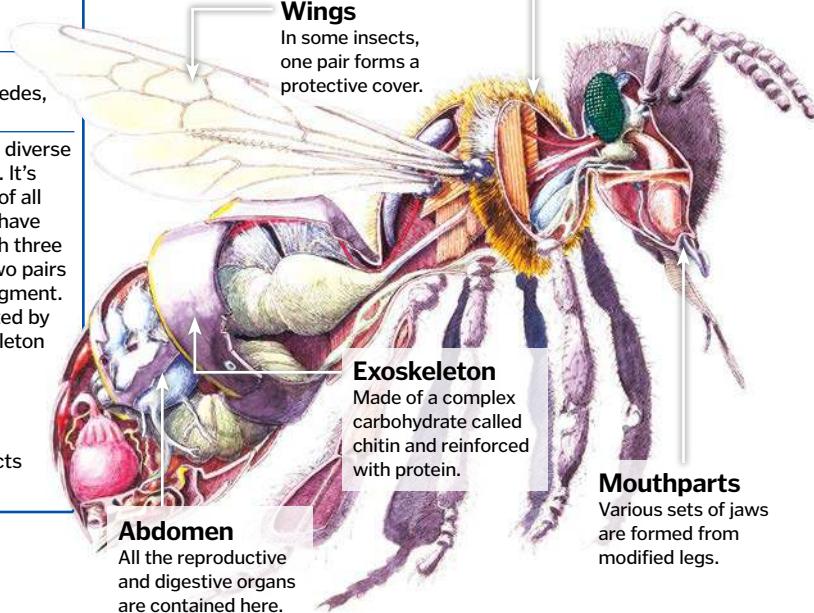
### GASTROPODS

**Phylum:** Mollusca

**Phylum also includes:**

Clams, razorshells, oysters, squid, octopuses

**Info:** Gastropods are slugs, snails and limpets. Snails have a spiral shell large enough for them to retreat into, to prevent them drying out or being eaten. They use a chainsaw arrangement of microscopic teeth (a radula) to graze on algae and plants. Marine snails use their radula plus secreted acid to drill through the shells of other molluscs.

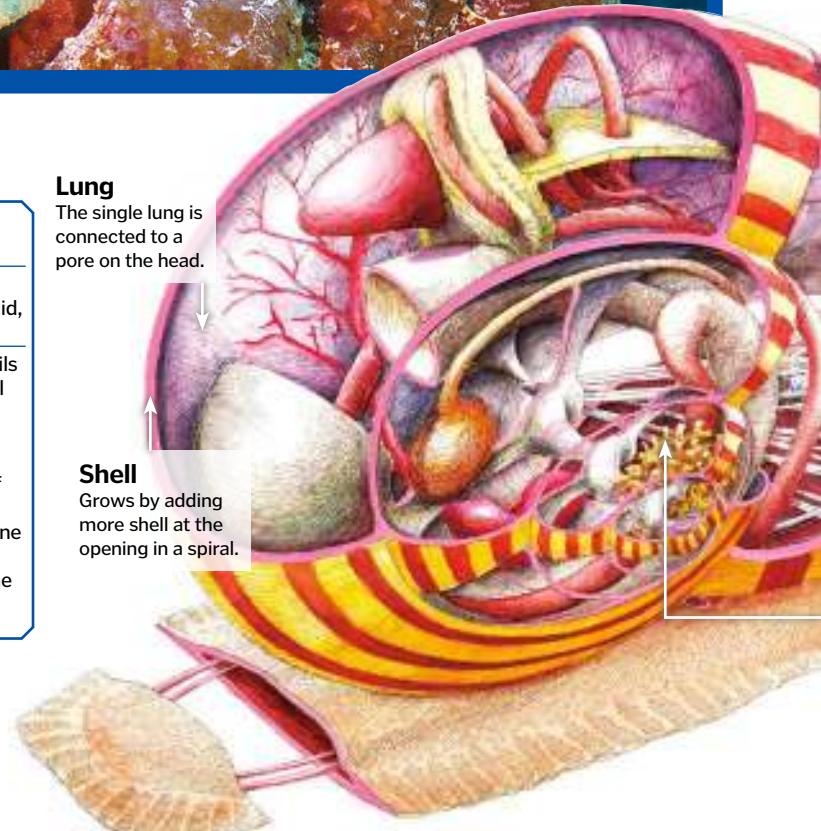


### Lung

The single lung is connected to a pore on the head.

### Shell

Grows by adding more shell at the opening in a spiral.



**DID YOU KNOW?** The total weight of all the ants in the world is the same as the total weight of all humans

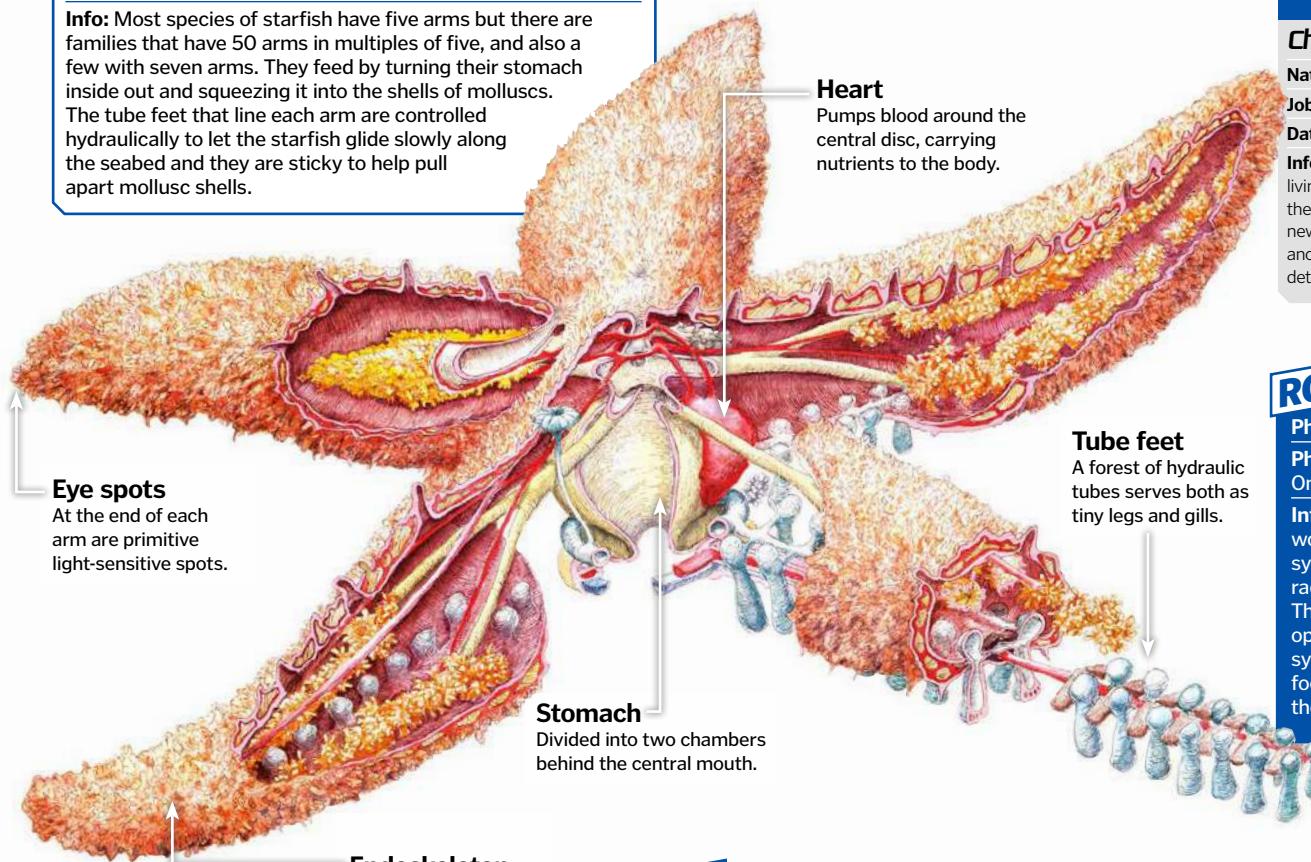
## SEA STARS

**Phylum:** Echinodermata

**Phylum also includes:**

Brittle stars, sea urchins, sea lilies, sea cucumbers

**Info:** Most species of starfish have five arms but there are families that have 50 arms in multiples of five, and also a few with seven arms. They feed by turning their stomach inside out and squeezing it into the shells of molluscs. The tube feet that line each arm are controlled hydraulically to let the starfish glide slowly along the seabed and they are sticky to help pull apart mollusc shells.



**"Sea stars feed by turning their stomach inside out"**

## KEY PLAYER

**Charles Darwin**

**Nationality:** British

**Job title:** Naturalist



**Date:** 1809-1882

**Info:** Established all living species are part of the same family tree. Evolution causes new species to branch away from ancestral ones. Natural selection determines survival and extinction.

## ROUNDWORMS

**Phylum:** Nematoda

**Phylum also includes:**

Only roundworms

**Info:** Nematodes are thin worms with a bilaterally symmetrical body and a radially symmetrical head. Their digestive system has an opening at each end with a system of valves that pushes food through the intestine as the worm wriggles around.

## CORALS

**Phylum:** Cnidaria

**Phylum also includes:**

Jellyfish, sea wasps, freshwater hydra

**Info:** Corals and sea anemones belong to the class Anthozoa. They have a jellyfish-like larval stage that settles onto a rock and permanently anchors there. Adults have a single opening for the digestive system, which is surrounded by a fringe of often colourful tentacles. These are lined with stinging cells called nematocysts that harpoon tiny plankton. Reef-building corals also have symbiotic algae within their bodies that help them to secrete the protective calcium carbonate skeletons which make up this biodiverse habitat.



## TAPEWORMS

**Phylum:** Platyhelminthes

**Phylum also includes:**

Flukes, flatworms

**Info:** The Cestoda, or tapeworms, are intestinal parasites of vertebrates. They have absolutely no digestive system and are hermaphroditic. They absorb nutrients from their host and reproduce by detaching the egg-filled tail segments into the host's faeces.

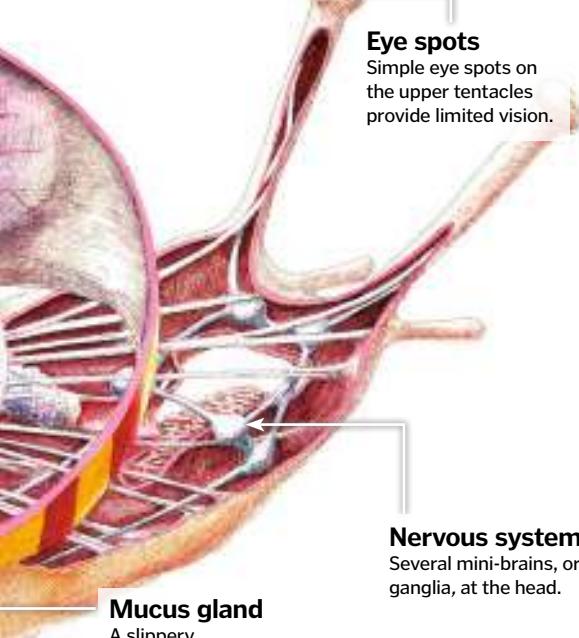
## CLITELLATA

**Phylum:** Annelida

**Phylum also includes:**

Lugworms, ragworms

**Info:** The Clitellata is the class that includes the common earthworm. They have segmented bodies with internal dividing walls. The gut, circulatory and nervous system run the length of the worm, but other organs are repeated in each of the body segments.





# "Allopatric speciation occurs when animals are geographically isolated"

the same species are those that can interbreed to produce healthy offspring. You can cross a lion and a tiger to produce a liger, but this hybrid animal is almost always sterile, because lions and tigers belong to different species (*Panthera leo* and *P. tigris*, respectively).

Charles Darwin's crucial insight was to see that new species arose when an existing population split into two groups that stopped breeding with each other. This can happen in two main ways. Allopatric speciation occurs when animals are geographically isolated. The islands of the Galápagos archipelago, for example, are just close enough together to allow birds to fly between them – when blown off course by a severe storm, for instance – but far enough apart to prevent the populations of two islands from routinely interbreeding.

Over time, the random shuffling of genes from generation to generation, as well as natural selection caused by the different conditions on each island, leads the populations to evolve in completely different directions. Darwin found that each isle had its own unique species of mockingbird. An ancestral species of mockingbird had split into four new species. Similarly, the chimpanzee and bonobo species formed when the Congo River divided the population of ancestral apes in half, around 2 million years ago.

The opposite of allopatric speciation is sympatric speciation. This is where a species splits into two distinct forms that don't interbreed, even though they still share the same territory. An example of this happening today is the American apple maggot fly (*Rhagoletis pomonella*). Despite its name, the larvae of this species originally fed on hawthorn berries. When the apple was introduced to America around 200 years ago, a few flies must have laid their eggs on apples instead. Female flies normally choose to lay their eggs on the same fruit as they grew up in, and male flies generally mate with females near to the fruit that they grew up in. This means that even though the two populations of flies could theoretically interbreed, in practice they do not.

In the last two centuries, some genetic differences between the two populations have emerged and eventually *R. pomonella* could

## Vertebrate biology

Discover what characteristics are shared by creatures with a backbone

### FISH

#### Phylum: Chordata

**Info:** Most fish belong to the class Actinopterygii, which are the bony, ray-finned fishes. The other main class of fish contains the sharks, rays and skate, or Chondrichthyes. The two groups aren't actually any more closely related to each other than, say, birds and reptiles. The bony fishes have a calcified skeleton, swim bladder and large scales on the skin. Sharks may look externally quite similar to bony fish, however their body structure is quite different, as we see here.

#### Cartilage

Without calcium carbonate, Chondrichthyes bones are flexible and half the weight.

#### Spiral valve

Increases the surface area to compensate for the short intestine.

### REPTILES

#### Phylum: Chordata

**Info:** Reptiles are air-breathing vertebrates that lay their eggs on land, though some actually live in water. They have scaly skin, and modern reptiles are cold-blooded, although some large prehistoric ones may have been warm-blooded. Reptiles are a leftover category; rather than having defining features of their own, they are classified as the vertebrates that produce eggs with an amniotic sac that aren't mammals or birds.

### AMPHIBIANS

#### Phylum: Chordata

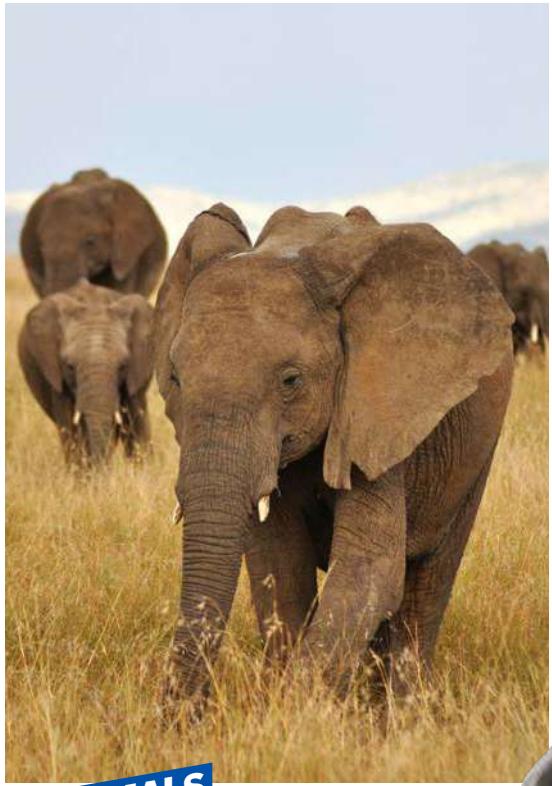
**Info:** Amphibians were the first vertebrates to emerge onto the land. They still lay their eggs into water and most have an aquatic larval stage. The adults have air-breathing lungs but can also breathe underwater through their skin. They are cold-blooded and need to keep their skin moist. Amphibians have tiny teeth or none at all, but often have a large muscular tongue that can be used to catch prey.



## Pain in the class

The duck-billed platypus lays eggs, but also has a bill and webbed feet. It also has mammary glands and fur. Is it a bird or a mammal? It's actually a monotreme, once treated as a separate group on the same level as mammals. Nowadays taxonomists class them as a subgroup of mammals. Another problem animal is *Peripatus*, which looks like a caterpillar but actually has more in common

with an earthworm. Its evolutionary journey has got stuck halfway between the annelids and arthropods, which makes it hard to know which group to put it in. The lungfish are a similar halfway house between the bony fish and the amphibians. Worst are the microscopic *Myxozoa* that have variously been classed as protzoa, worms and jellyfish – though they actually look nothing like any of them!



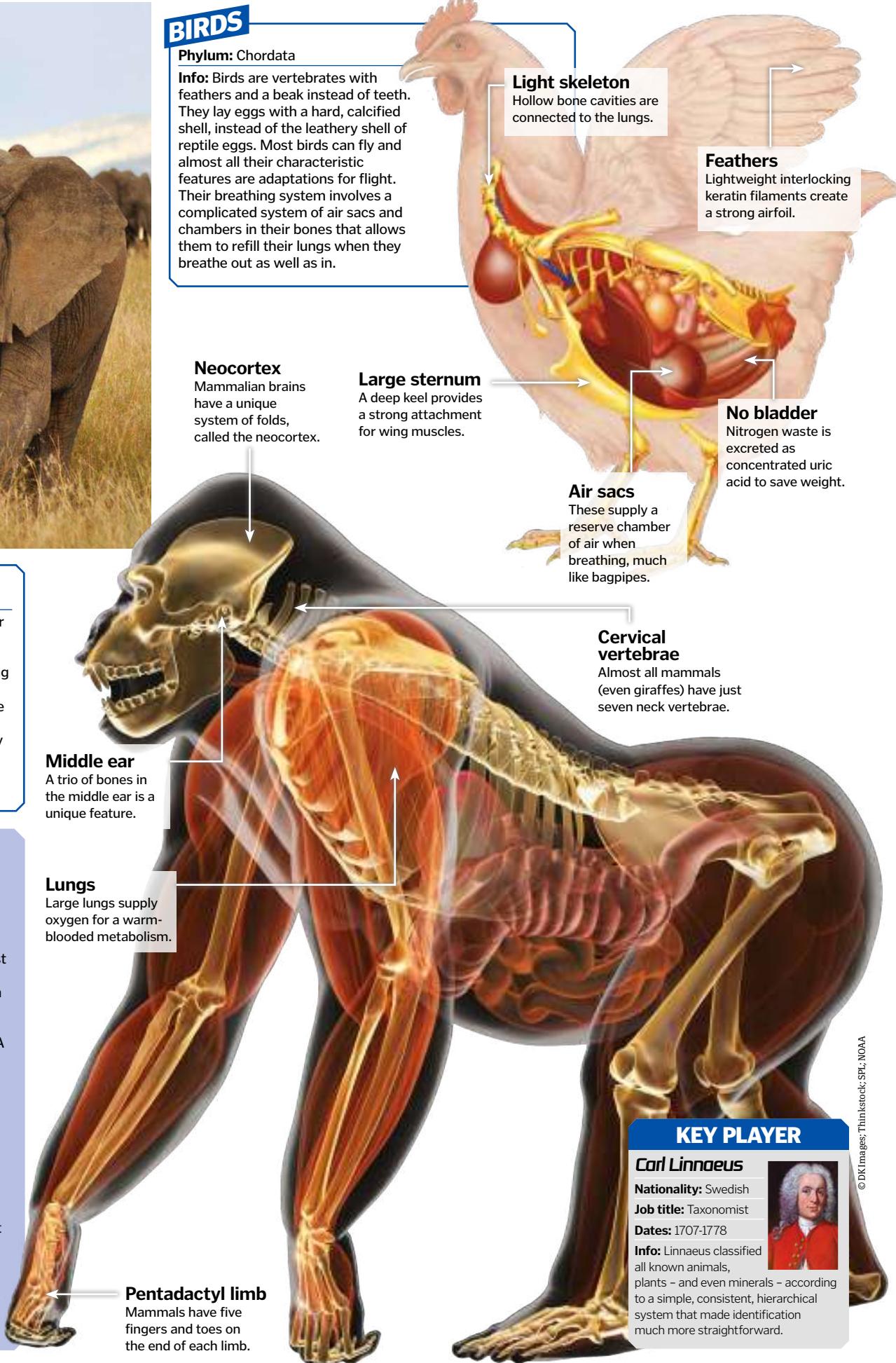
## MAMMALS

### Phylum: Chordata

**Info:** Mammals are defined by their body hair and their mammary glands for feeding young. Most mammals nourish the embryo using a placenta that grows out of the uterus. Monotremes are a primitive group of mammals that comprise the platypus and echidnas; they lay eggs, but even then the egg develops for a long time inside the mother and is nourished by her.

## A molecular family tree

A good classification system doesn't just group animals that *look* similar; it groups those that are related evolutionarily. The best way to do this is by comparing their DNA. All animal cells contain organelles called mitochondria and these have their own DNA. Assuming that mitochondrial DNA only changes as a result of random mutation, the amount of mutation over evolutionary time can be used to create a family tree. Molecular phylogenetics is the scientific discipline that compares the mitochondrial DNA barcode of different animals, and groups the most similar ones together. It is certainly not a perfect system though because it has to make some assumptions about the background mutation rate, and we now know that mitochondria can also acquire new DNA from other sources by horizontal gene transfer.





# BIG CAT ATTACK



Find out what makes these cats such effective killing machines in a formidable show of muscle, fur and teeth

The world's big cats are majestic powerhouses of muscle and strength, with acute senses and killer instincts. The true big cats are the four largest species of the genus 'Panthera': lions, tigers, jaguars and leopards. However, there are also many other large cat species that have incredible hunting abilities, one of which is the mighty cheetah.

Mostly found in sub-Saharan Africa, cheetahs are super-streamlined and built for killing on the fly. They have specialised muscle fibres to power their long limbs, black 'tear lines' to help counteract glare from the African sun and a spotted coat to keep them camouflaged in the long grasses.

Although their spots may look similar at first glance, a closer look reveals that leopards (which often share the cheetah's habitat) have very different markings. Leopard spots are more detailed, featuring clusters of black and brown rosettes rather than the cheetah's simple black ovals. These markings mimic the shifting shadows of trees and leaves, allowing the cheetah to blend into the background. If one's stalking you, you won't know about it until it's too late! Leopards have a wider range, and can be found in forests, deserts, mountains and grasslands throughout Africa and Asia.

## "Lions can even take down the largest animals on land: elephants"

Back on the savannah, it's the lions that have the edge. When they're feeling really plucky, these cats can even take down the largest animals on land: elephants. They can do this because they have evolved to work together. Hunting as a group allows lions to take on much larger animals, surrounding and overwhelming them. It's thought that this ability to hunt cooperatively is due to a highly developed frontal cortex – the part of the brain that deals with problem solving and social behaviour. This is particularly evident in lionesses, the pride members that do the majority of the hunting. These amazing creatures stake a claim to be the most intelligent of the big cats. Competition is vast, though.

As the largest of the big cats, tigers are supreme predators. Found in swamps, grasslands and rainforests throughout Southeast Asia, China and the mountains of far-east Russia, these striped heavyweights hunt alone, relying on their camouflage and stealth to track down prey and catch it with the element of surprise.

Read on to get under the skin of all of these fierce felines, and find out more about the physiology of a big cat attack.

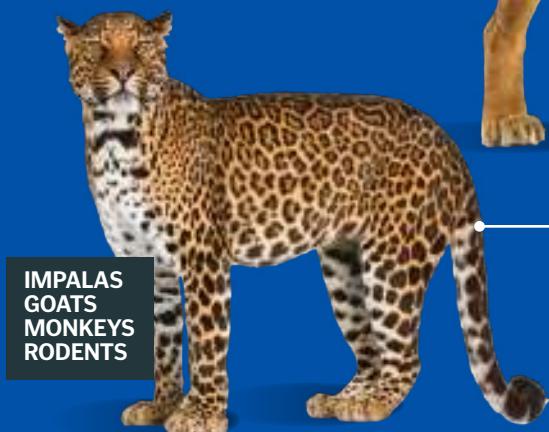
## What's on the menu?

Each giant feline has a taste for something different

### Lion

The 'king of the jungle' can essentially eat anything it can catch, but given that lions are found on the plains of sub-Saharan Africa, they commonly eat the animals nearby. Like all big cats, lions need a high-protein, all-meat diet.

WILDEBEESTS  
ZEBRAS  
CAPE BUFFALOS  
ANTELOPES  
GIRAFFES



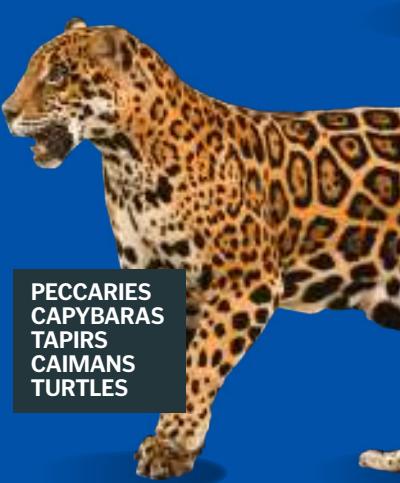
### Leopard

Hunting alone, leopards search out mostly smaller, hooved animals although they will occasionally prey on monkeys and other smaller creatures if the pickings are slim. In general these smaller prey are easier to catch single-handed and drag into the treetops for eating.

### Tiger

The largest of the big cats, tigers need their fill of meat. Their favourite prey depends on their habitat, but they primarily eat larger mammals as they have more fat and protein to sustain the tigers' needs. However, when times are tight, tigers will tuck into anything, from fish to rodents.

WILD BOARS  
DEER  
ANTELOPES  
WATER BUFFALOS



### Jaguar

Not shy of a challenge, jaguars have a very varied diet. Their amazing hunting ability allows them to take down large forest-dwelling mammals and their willingness to take to water provides a whole other selection of prey items.

### Cheetahs

While not officially a big cat species of the *Panthera* genus, cheetahs are formidable felines. They use speed and strength to catch their main prey, ungulates, but can also supplement their diets with smaller creatures such as hares and even birds.

GAZELLES  
IMPALAS  
HARES  
WARTHOGS





# The need for speed

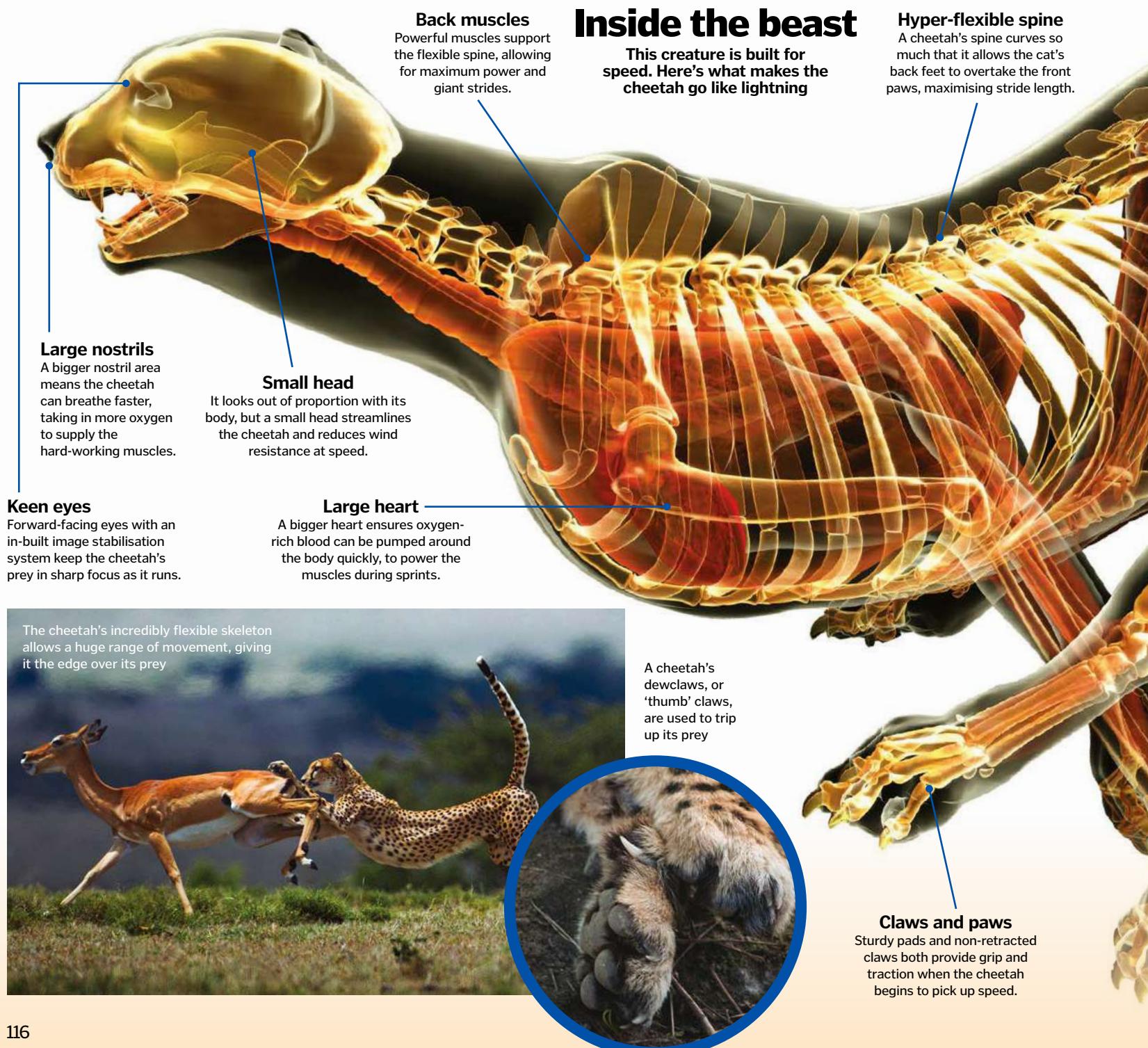
For some big cats, speed is the name of the game

Have you ever looked at a picture of the African savannah, and seen lions walking among a group of impalas and wondered why the impalas are just grazing away, instead of running for their lives? This is because the impalas know that a single lion in the open isn't fast enough and they can easily outrun them. The lions know this too, and won't waste their energy trying. For other big cats though, speed is everything. Leopards use

speed for a quick-fire burst, usually after they have expertly stalked their prey and got within striking distance. Similarly, tigers use a swift leap or lunge to grab their prey once it's within reach. The element of surprise is key!

Cheetahs are the real athletes of the big cats, though. They can sprint for long distances and accelerate quickly, with some records clocking up a sustained distance of around four kilometres

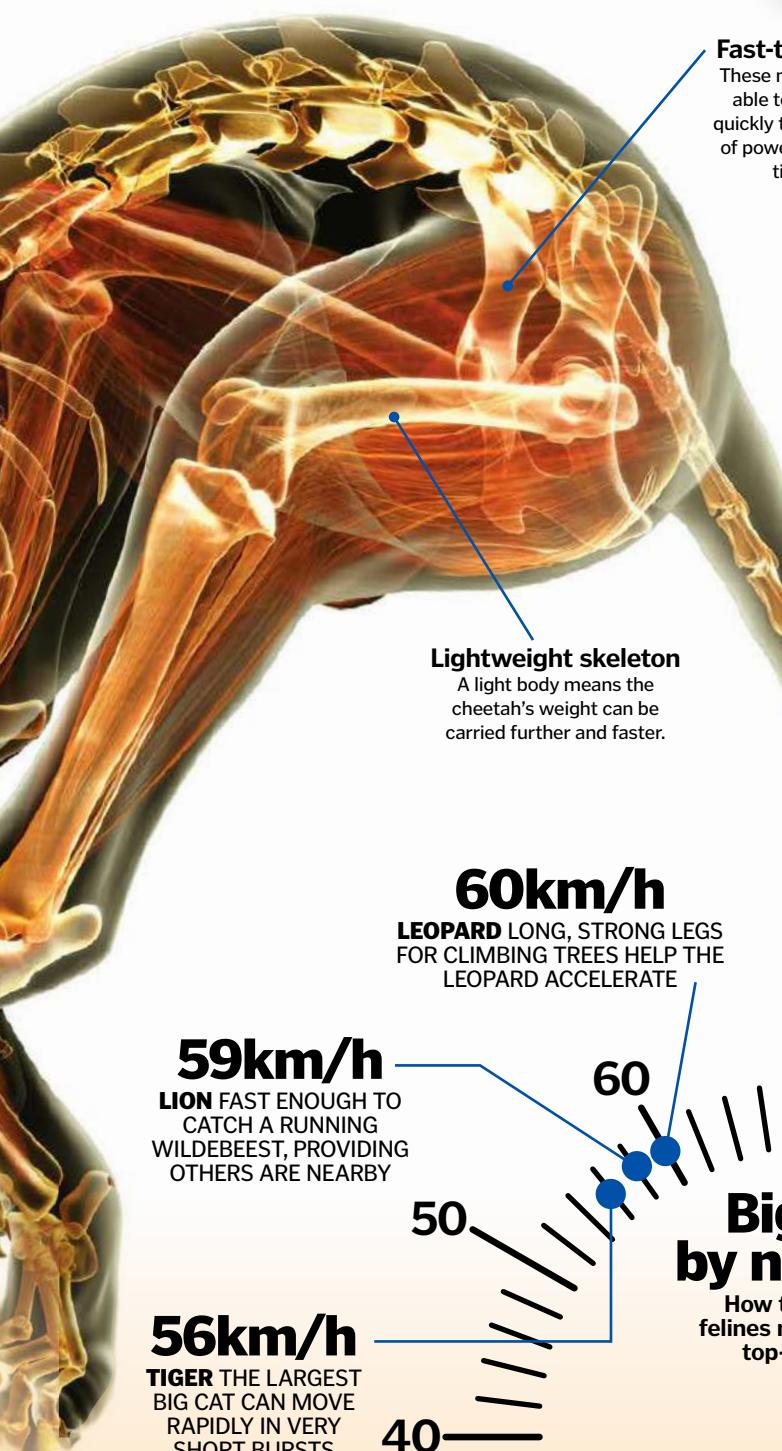
and an acceleration of 0 to 75 kilometres per hour in two seconds. However, they can only stay at their top speed for around 400 to 800 metres, so they must plan their attack carefully. They will approach downwind from the prey so that their scent doesn't give them away, and then launch an ambush at lightning speed. If they time this well, they will successfully outpace their prey and go in for the kill.



## Why cheetahs don't roar

Only the 'true' big cats, those in the genus *Panthera* (lions, tigers, leopards and jaguars) can let out a deep, guttural roar. This is because the part of their voice box known as the hyoid bone is flexible. Coupled with a stretchable ligament it makes a sound-producing passage and the more the ligament stretches, the deeper the pitch.

Cheetahs, along with other 'smaller' big cats like pumas, instead have a similar voice-box anatomy to house cats. The hyoid bone is completely hardened, meaning roars are impossible to generate. The voice box is a fixed structure, but this allows them to purr – something that the *Panthera* cats cannot do. Interestingly, the exception to the rule is the snow leopard; although it is a member of the *Panthera* genus and has a flexible hyoid, this cat can neither roar nor purr! Instead, it makes a 'chuffing' sound.



**60km/h**

**LEOPARD** LONG, STRONG LEGS FOR CLIMBING TREES HELP THE LEOPARD ACCELERATE

**59km/h**

**LION** FAST ENOUGH TO CATCH A RUNNING WILDEBEEST, PROVIDING OTHERS ARE NEARBY

**56km/h**

**TIGER** THE LARGEST BIG CAT CAN MOVE RAPIDLY IN VERY SHORT BURSTS

## Big cats by numbers

How the other fierce felines measure up in the top-speed stakes

**80km/h**

**JAGUAR** STILL BEHIND THE MIGHTY CHEETAH, BUT THE FASTEST OF THE REST

**94km/h**

**CHEETAH** FASTEST ANIMAL ON LAND



# Strategy of the hunt

Each predator plays to its strengths, executing different tactics to hunt and catch their prey

Lions use their sheer size, brute strength and power in numbers to go after large prey items, such as buffalos, zebras and giraffes. They both stalk prey and attack en masse, coming at prey from different angles to startle and confuse. Lions will also scavenge, stealing kills off other predators such as hyenas and cheetahs.

All the other big cat species are solitary hunters, and need to employ a very different and more fine-tuned approach. Cheetahs use their highly specialised bodies to generate massive thrust, using propulsion and attuned senses to home in on their quarry. They then use their dewclaw to trip the prey, causing it to stumble and fall.

Tigers will use their keen senses and superb camouflage to stay hidden in the undergrowth. They stalk prey until close enough to strike – lunging at it from around six metres away. With razor sharp claws outstretched, any animal in this cat's sights may struggle to get away! These cats can even launch attacks from water. The tiger will then use its bulk to grapple with its prey.

Snow leopards are ambush predators and will use their rocky, mountainous home to their advantage. They will often creep up on prey near cliff ledges and drop onto them from above.

Leopards and jaguars have similar strategies. To locate prey in the dark, leopards have excellent night vision, around seven times better than ours. They rely on their hypersensitive paws to feel the terrain, ensuring that no twig-snaps or leaf rustles give away their position. A quick lunge and a powerful bite are enough to seal the deal. However, due to their climbing preferences, these cats will employ the 'drop from above' tactic too. Leopards and jaguars aren't afraid of swimming and will happily get wet to secure a meal, or sometimes they won't bother hunting at all, and will keenly scavenge a meal.

## Hunting school

Lesson number one: eat, or be eaten! How young cubs learn to be predators



### Lion

Play fighting is a big part of learning. Lions in the pride will encourage cubs to pounce and stalk one another before being introduced to live prey.



### Tiger

By the time they reach 18 months, tiger cubs will be skilled hunters. They learn through watching their mother and finishing off her contests.



### Leopard

The essential skills that leopard mothers teach their young include how to pin down animals, and the best place to clamp down on a throat.



Lionesses do the majority of the hunting for the pride

### Lionesses

There are around 12 lionesses in a pride unit, and they are usually all related.

### Young males

When they reach maturity, young males are often ousted and leave the pride to form bachelor groups before they join their own pride.

### Time to leave

If a male or female is injured or too old and can't perform their role, they are pushed out of the pride.

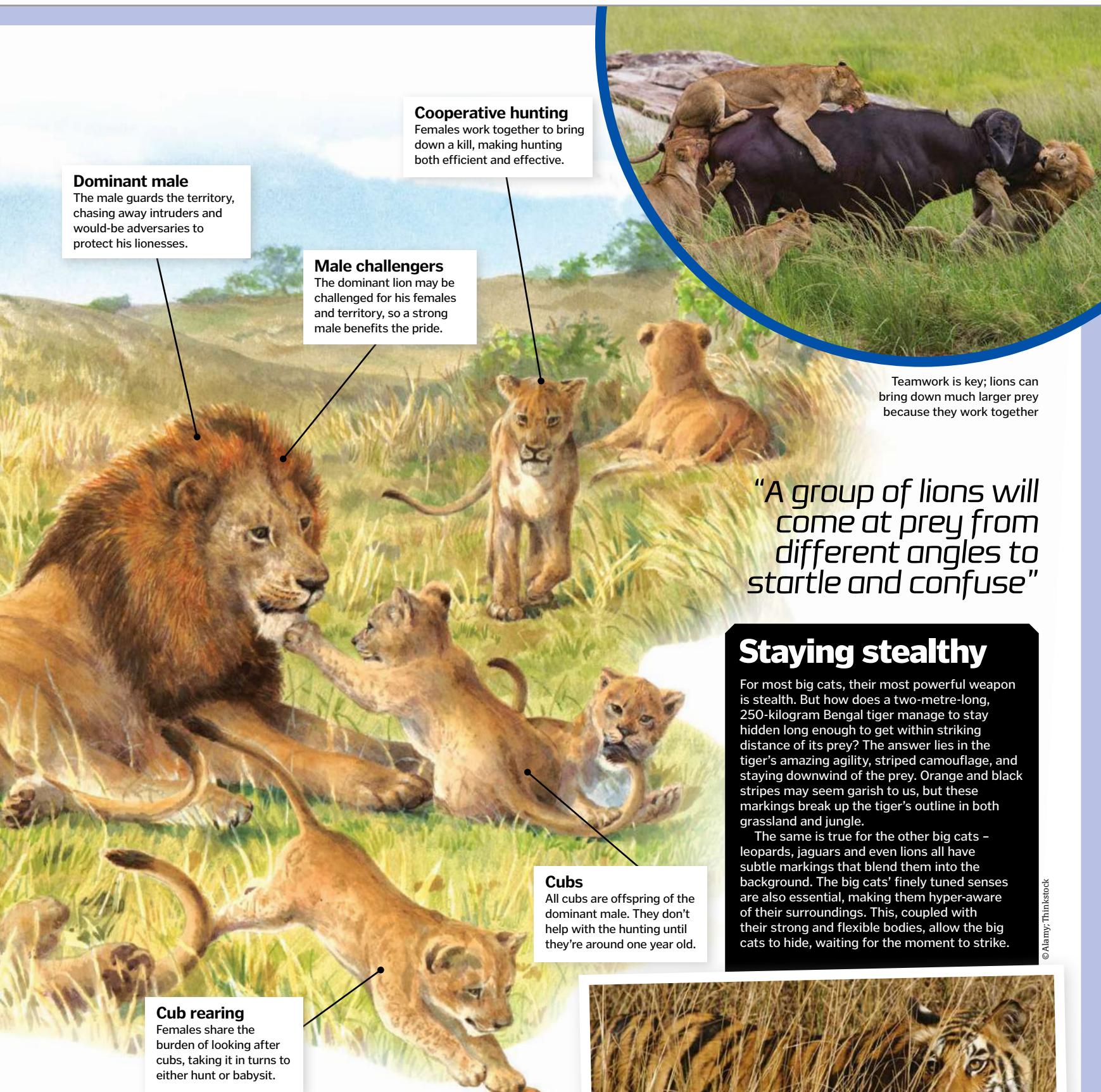
### Safety in numbers

Lions live in open grasslands, where a kill draws easy attention. The pride works together to defend food from scavengers.

**"Big cats' finely tuned senses make them hyper-aware of their surroundings"**

**Mealtime hierarchy**  
After a kill, the males always eat first. Then the females will eat their fill and the cubs follow.

**DID YOU KNOW?** Leopards are strong climbers and can drag their prey up into the trees to eat



## "A group of lions will come at prey from different angles to startle and confuse"

### Staying stealthy

For most big cats, their most powerful weapon is stealth. But how does a two-metre-long, 250-kilogram Bengal tiger manage to stay hidden long enough to get within striking distance of its prey? The answer lies in the tiger's amazing agility, striped camouflage, and staying downwind of the prey. Orange and black stripes may seem garish to us, but these markings break up the tiger's outline in both grassland and jungle.

The same is true for the other big cats – leopards, jaguars and even lions all have subtle markings that blend them into the background. The big cats' finely tuned senses are also essential, making them hyper-aware of their surroundings. This, coupled with their strong and flexible bodies, allow the big cats to hide, waiting for the moment to strike.



**Jaguar**  
Young jaguars stay with their mothers for two years or more. They watch her every move and learn to hunt by her example.



**Cheetah**  
A mother cheetah will teach her cubs to hunt by bringing young or weak prey back to their lair. The cubs can then practise chasing and catching.



A striped coat helps tigers blend into the undergrowth



# In for the kill

After the take-down comes the dispatch, a grizzly yet necessary part of the hunt

When big cats get a hold on their prey and they have paws on the prize, the next step is crucial: the kill. Almost all of the big cats use the method of asphyxiation to kill their prey. This is the quickest method to make sure that the prey does not get away, and that all of the energy these animals have expended on stalking and chasing doesn't go to waste. Big cats have incredibly strong jaws, powered by efficient musculature in their head and neck. To complement a strong jaw are sets of super-sharp teeth, perfect for piercing flesh and holding prey down.

For lions, the kill is usually a team effort. Because they often hunt in groups, one lion will frequently assume the role of clamping its colossal jaws around a prey animal's snout, attempting to suffocate it while the rest of the hunting team hang on its flanks to bring it to the

ground. This is sometimes called the 'lion kiss of death', and they can bring down very large prey in this way.

It's very often thought that big cats automatically 'go for the jugular' to dispatch their prey, but this isn't the case. When their teeth aim for the neck, it's the animal's windpipe that the cat is aiming for, rather than the veins. Their vice-like jaws clamp onto the windpipe and crush it, suffocating the prey for a quick kill.

Tigers use this method for larger prey. By biting the neck and using the animal's strength against itself in order to drag it to the ground, they can bring down very large animals single-handedly. For smaller critters they may bite the nape of the neck in order to sever the spinal column. Leopards also use this super-effective technique.

Tigers use their strong front legs to tackle and immobilise their prey, before biting down on the neck



Jaguars, on the other hand, do things a little differently; these animals are the only big cats to prey on reptiles, and it's thought that their killing style has evolved to take down dangerous and armoured prey. The jaguar, instead of going for the throat, directly bites its prey in the back of the neck or head, severing the spinal cord and puncturing the braincase.

By using this technique, the jaguar can get past the thick hides of caiman and pierce the strong shells of turtles.

## Killer blow

How a leopard secures its prey in one huge burst of power

**Muscular legs**  
Strong legs provide bursts of energy for jumps and lunges.

**Strong bite**  
The leopard holds its prey at the neck, where it delivers the killer blow.

**Eye on the prize**  
Leopards' eyes have a specialised membrane that allows them to focus even in low light.

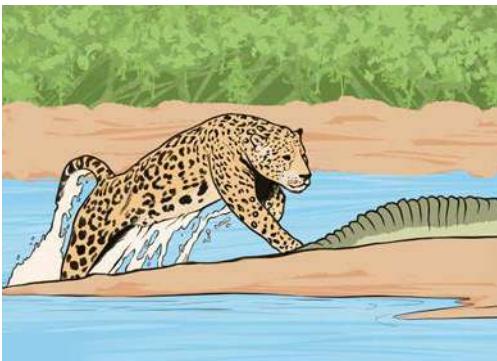
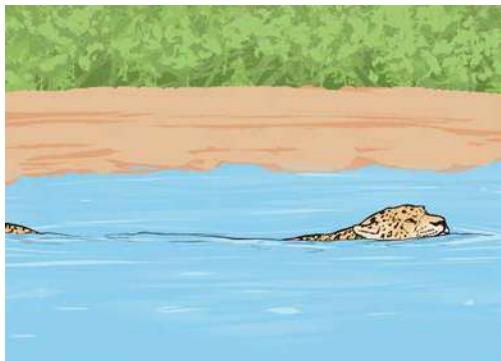
**Sharp claws**  
Claws help immobilise prey and climb to safety.

*"Their vice-like jaws clamp onto the windpipe and crush it, suffocating the prey for a quick kill"*



## Jaguar vs caiman

These cats aren't scared of water, nor the scaly, snappy reptiles that live within

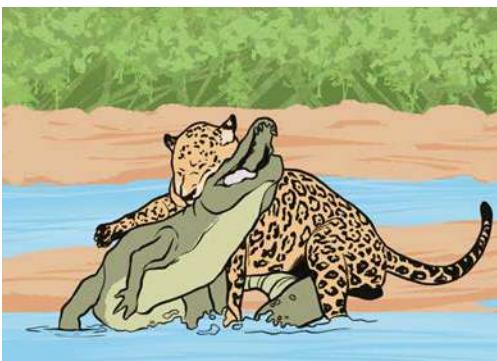
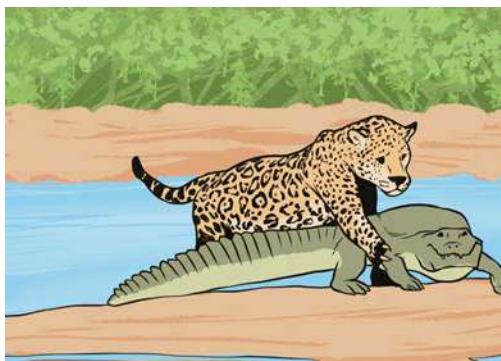


### 1 The swim

Jaguars are great swimmers. With prey in his sights, this jaguar chooses a water approach, making sure to swim stealthily with no splashes or sudden moves.

### 2 The stalk

Exiting the water, the jaguar has the element of surprise on the unsuspecting caiman. He stalks for one second more to get closer.



### 3 The attack

The caiman has little time to run before the jaguar takes a leap onto him. The jaguar again has the element of surprise and immobilises the caiman.

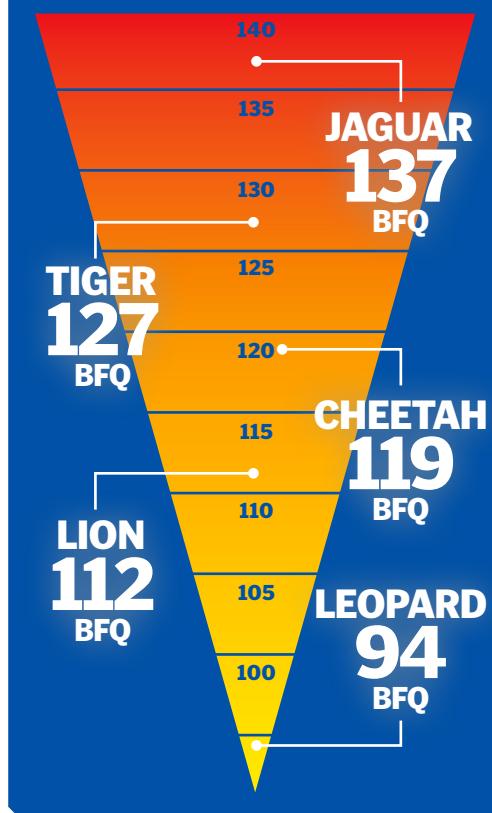
### 4 The death blow

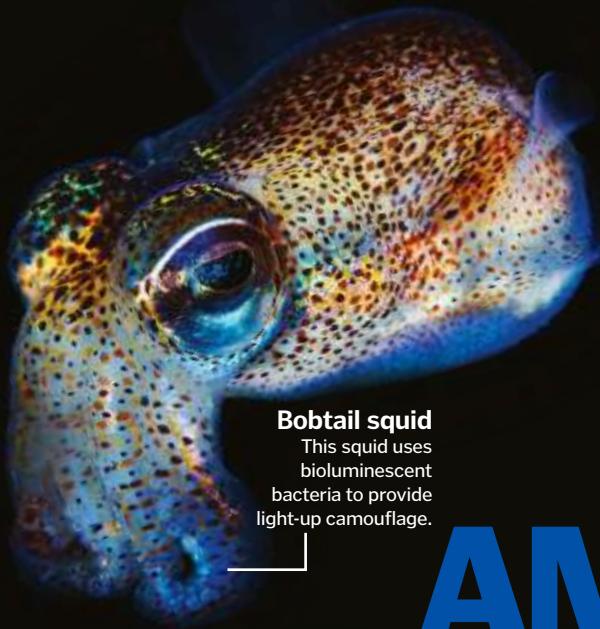
A sharp bite into the braincase at the back of the caiman's head instantly immobilises the reptile. A successful hunt for the jaguar!

## Big cat bite force

Check out the sheer power of these formidable predators

Bite force quotient (BFQ) is a measure of an animal's bite force relative to its body size. For comparison, a domestic cat's BFQ is 58.





**Bobtail squid**

This squid uses bioluminescent bacteria to provide light-up camouflage.



**Jellyfish**

Some jellyfish species use flashes of light to scare off potential predators.



**Scorpion**

Scorpions fluoresce under UV light, but no one really knows why.

# AMAZING GLOW-IN- THE-DARK ANIMALS

Hit the switch and  
adjust your eyes to the  
multicolour world of  
natural light



**Firefly**

A light organ on this bug's back produces its distinctive flashes.



**Coral reef**

Many coral reef creatures use fluorescence to survive.

Imagine walking through a forest at night and encountering a swarm of dancing lights floating in the air. It may look like magic, but it is one of the most astounding features of the natural world: bioluminescence. The flying flickers of light are a biochemical reaction exhibited by tiny fireflies, as they light up the night in their efforts to find a mate.

Bioluminescence is found throughout the animal kingdom and beyond, and the most extensive array of glow-in-the-dark creatures can be found in the ocean. Yet, interestingly, freshwater habitats have almost no bioluminescent organisms.

Although modern science has allowed us to explore the inner workings of how this incredible biology occurs, bioluminescence has been fascinating humans for thousands of years.

References to natural creatures glowing in the dark appear in the folklore of many different cultures, in Scandinavia, China and India to name a few. In the fourth century BCE, ancient Greek philosopher Aristotle noted, "some things, though they are not in their nature fire nor any species of fire, yet seem to produce light." Similarly, during the first century CE, Roman scholar Pliny the Elder even documented that he took the slime of a jellyfish from the Bay of Naples and rubbed it on his walking stick, where it lit the way "like a torch."

As Aristotle himself noticed, bioluminescence is a 'cold light', which means that unlike the glow that is produced by electrical light bulbs, which also produces waste heat energy, the bioluminescent reaction is almost 100 per cent efficient and produces very little heat. There are two ways that animals are able to produce this light: by possessing the right biological means to make it themselves, or by hosting bioluminescent bacteria that work with the animal to provide their flashy light show. These bioluminescent bacteria can also be free-living, or parasitic, attaching themselves to a host and making it glow unwittingly.

One animal that has a mutually beneficial relationship with these bacteria is the tiny bobtail squid, a cephalopod just a few centimetres long, found in coastal waters of the Pacific. The squid uses the bacteria's blue-green glow to camouflage itself in the water column by matching the glow of moonlight from above - a technique known as counter illumination. In return, the squid's body provides the bacteria

with a sugary solution to feed on. Every morning, the squid will expel 95 per cent of its bioluminescent bacteria, ensuring that it stops glowing while it rests. By the time night returns, the bacteria have repopulated, reaching a large enough concentration to begin glowing again. This is also an interesting use of bioluminescence as camouflage, rather than to light the way in darkness.

Bioluminescent creatures that don't rely on luminous bacteria create their own light via chemical reactions. These animals often have specialist organs called photophores in which organic molecules known as luciferin react with oxygen to produce photons of visible light. These reactions can be initiated by various factors, including chemical, neurological or mechanical triggers.

Bioluminescence is not the only method employed by the animal kingdom to glow in the dark. Many animals also shine through fluorescence, where light is absorbed and then emitted at a different wavelength. For example, under a UV light, scorpions appear a neon turquoise colour.

Various species of corals, jellyfish and crustaceans also have fluorescent properties, as does the Japanese eel - which is one of the only known vertebrates to exhibit this trait.

On top of this, animals can also use phosphorescence, which is chemically similar to fluorescence, but the light is absorbed and (unlike fluorescence) still continues to glow once the light source is removed. Many sea creatures will exhibit a combination of the three light-up methods, but phosphorescence is often too weak to see with the naked eye or is overshadowed by the other two, much brighter, methods of natural illumination.

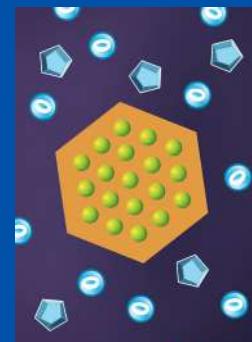
In the ocean, the glowing show of colour very often includes neon hues of blues and greens. This is because these are the wavelengths that travel the furthest in the depths, ensuring that a creature's lights are fit for purpose. However, the colours are also tailored to their specific function. Animals use their glow-in-the-dark capabilities for defence, to ward off predators or to dazzle attackers. Lights help to attract both food and mates, and can even provide a cloak of camouflage. It is possible that there are also benefits for the non-luminous ocean beings such as sperm whales, who dive so deep to hunt that scientists believe they may rely on the bioluminescence of their prey in order to track down a meal.

## The science behind bioluminescence

Bioluminescence is produced by a chemical reaction involving a molecule known as luciferin

### 1 Ingredients

In general, for a bioluminescent reaction to occur, an organism needs a luciferin molecule, luciferase (the catalyst which enhances the reaction) and oxygen to oxidise the luciferin.



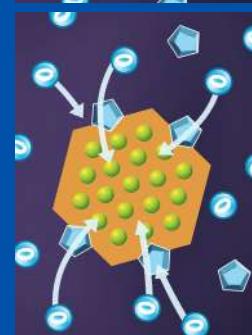
### 2 Catalyst

A catalyst is a substance that increases the rate of a chemical reaction. In this case, the catalyst is called luciferase. This is the general term for an enzyme that helps a light-emitting reaction to take place.



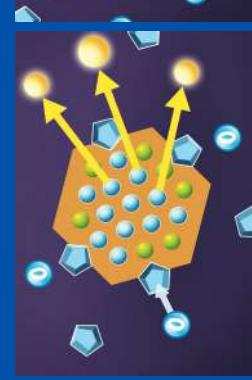
### 3 Oxidation occurs

The luciferase provides a pathway for the oxygen so that it can combine with the luciferin more easily. The oxygen then oxidises the luciferin by adding oxygen molecules to it.



### 4 Light is produced

When luciferin reacts with oxygen, photons of light are released. When this reaction happens collectively in a creature's photophores, it produces the amazing natural light displays.



### 5 Reaction by-products

The bioluminescent reaction results in by-products: carbon dioxide and a compound called oxyluciferin - the new name for the oxidised luciferin molecule.





## How natural illumination can benefit us

As a naturally occurring phenomenon, that in its simplest form requires just oxygen to work, bioluminescence can also have many applications in our everyday lives. We can harness this amazing light-emitting process for medical, military and commercial uses. Natural fluorescence, too, is being developed as an increasingly useful tool.

Scientists are able to use naturally fluorescent proteins to track the spread of viruses and diseases in rodents, and also to watch the development of cell tissue in amazing rainbow colours. This has potential for allowing us to understand and treat human disease.

We can also use our knowledge of bioluminescence to genetically modify plants so they glow. Although the science of this is still very much in its infancy, this use of bio-light could go as far as adapting trees to glow in place of streetlights, saving valuable fossil fuels. Scientists at Edinburgh University have already created glowing potatoes that illuminate under a black light when they are dehydrated, working as a marker for farmers to precisely monitor their crops. Although there is controversy surrounding genetically modified foods, the science behind such developments is still incredible.

There might also be military uses for bioluminescence. Certain species of plankton often bioluminesce when they are disturbed, which could give away the whereabouts of otherwise stealthy submarines, or disrupt other covert naval operations.

Then there are, of course, plenty of commercial applications to light up our daily lives as well. For example, biotech company BioLume in North Carolina hope to develop a range of incredible luminous sweet treats – such as lollies, chewing gum and drinks – as well as personal care products including toothpastes, soaps and bubble baths that glow in the dark.

## Lighting up the deep

Bioluminescence is found throughout the water column, from the surface waters to the deepest ocean trenches. As the light fades, the amount of biological illumination begins to increase. It's thought that around 90 per cent of deep-sea animals use some form of bioluminescent light to hunt, defend themselves and find mates.

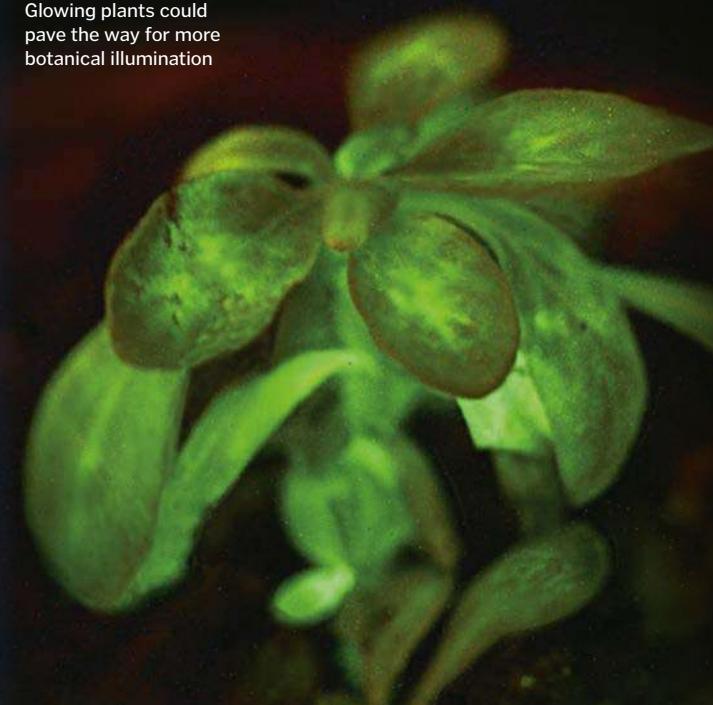
## Glowing mice

A fluorescent protein derived from jellyfish known as Green Fluorescent Protein (GFP) has revolutionised cell biology. It glows bright green under blue and UV light, and can be used as a versatile marker to highlight a huge array of biological processes. The protein can be cloned (so it doesn't need to be harvested from live jellyfish) and then the gene sequence for GFP can be added to an organism's genome. In turn, this makes specific areas of cells (that scientists want to study) 'glow'. This means scientists are much better able to witness and understand the growth of tissue, from nerve cells in the brain to the spread of cancerous tumours, which has huge potential in medical research.



Glowing mice could help researchers combat a huge array of diseases

Glowing plants could pave the way for more botanical illumination



## Glowing greenery

The company Bioglow has been working on an energy-saving alternative to streetlights, by developing a plant that glows on its own. Named Starlight Avatar, a pot plant called *Nicotiana alata* has had a gene for bioluminescent bacteria inserted into its genome, creating an 'autoluminescent' plant that emits a yellow-green light independently.

### Comb jelly

Despite their name, these tiny organisms are not jellyfish. Comb jellies have paddle-like appendages that propel them, which flash with rainbow light as they move. This happens when incident light is scattered through the moving cilia, but many species are also bioluminescent, capable of glowing blue-green.

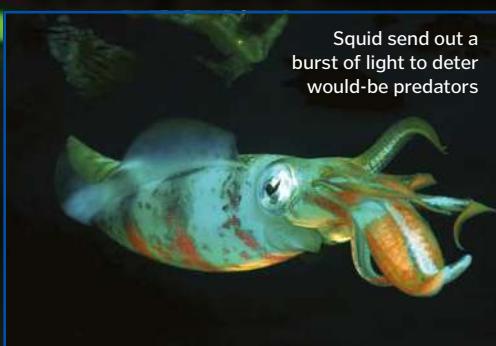


### Anglerfish

There are many species of anglerfish, with the majority possessing a large, bioluminescent lure, like a glowing fishing rod. This menacing appendage helps the females to attract prey. Male anglerfish are much smaller and do not have lures, instead they latch on to females like parasites and provide sperm for reproduction.



# Why do animals glow?



## DEFENCE

Defensive bioluminescence is used to deter predators. Creatures such as squid use a sudden burst of light to startle their attacker, and some animals also employ a 'smoke screen' effect to enable a quick getaway.

## OFFENCE

Bioluminescence can be used to attract prey, or to find it by lighting it up. Animals such as some siphonophores and flashlight fish will use their bioluminescence to lure prey towards them, and then enjoy the spoils.

## ATTRACTION

Bioluminescence plays a key role in the courtship of fireflies, who have light organs in their lower abdomen. Males perform a light show to attract females, who will flash back in response if they like what they see.

*"We can harness this amazing light-emitting process for medical, military and commercial uses"*



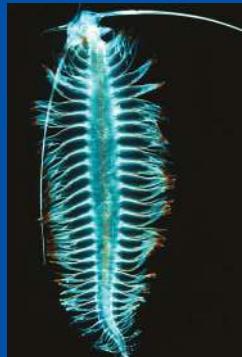
### Black dragonfish

This fearsome looking creature has light-producing cells along its entire length, and it can light up suddenly when disturbed or threatened. However, this fish has an extra trump card: it can glow with near-infrared light, which many other deep sea species are unable to detect, allowing it to launch stealth attacks upon its prey.



### Tomopteris

These beautiful-looking creatures are swimming polychaete worms. They have bioluminescent cells that allow them to flash bright colours, and there are species that can even produce yellow light, which is rare in the deep. Tomopteris are also capable of shooting bioluminescent particles that allows them to get away from predators.



### Mauve stinger jellyfish

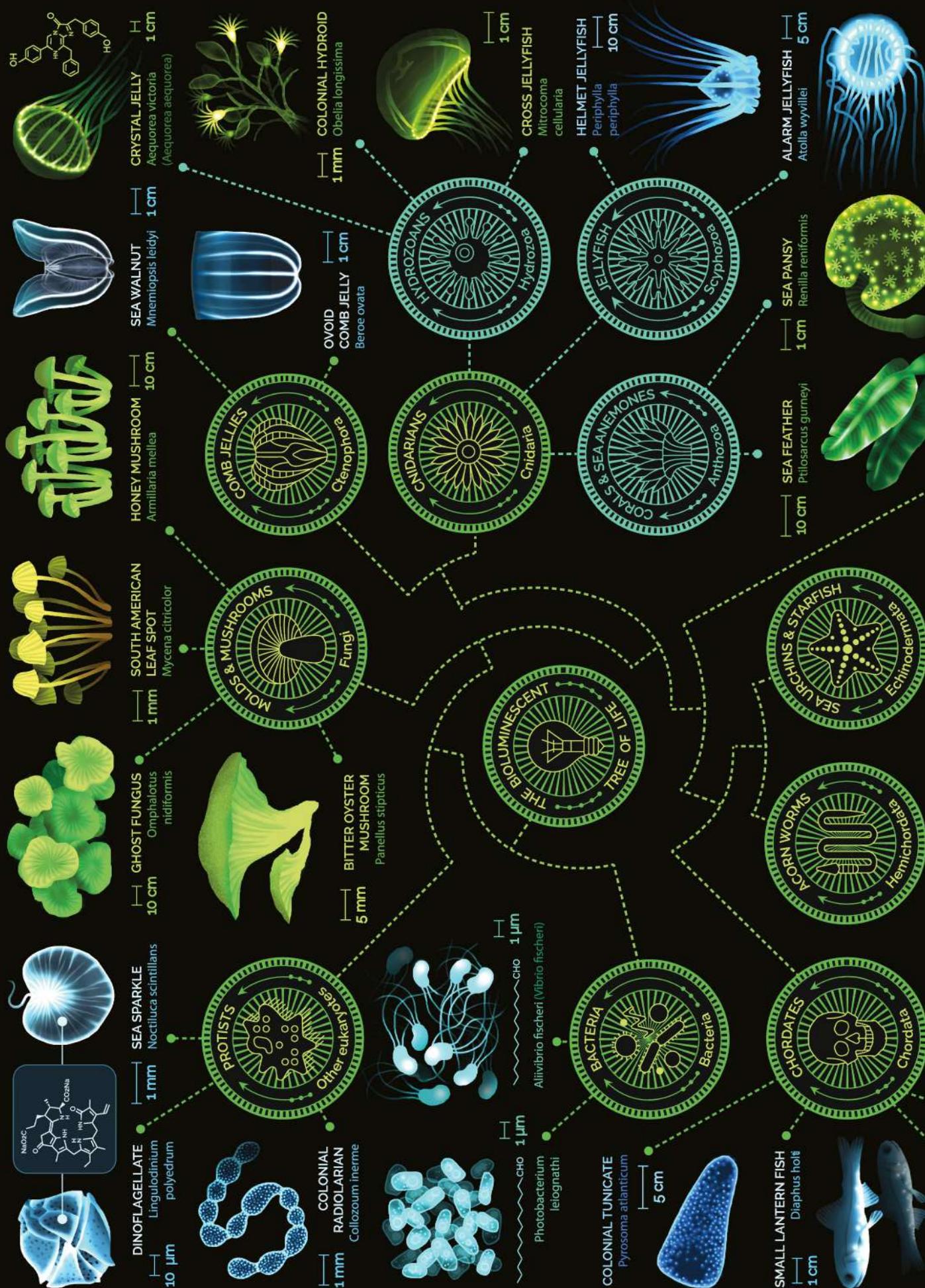
In German, the mauve stinger jellyfish's name translates as 'night light', reflecting its amazing bioluminescent capabilities. When it becomes startled or trapped, the flight response sets off the chemical reaction so it can release a glowing trail of mucus in its wake as it tries to make an escape.





# Living lights

The natural world is decorated with an army of organisms using bioluminescence to glow





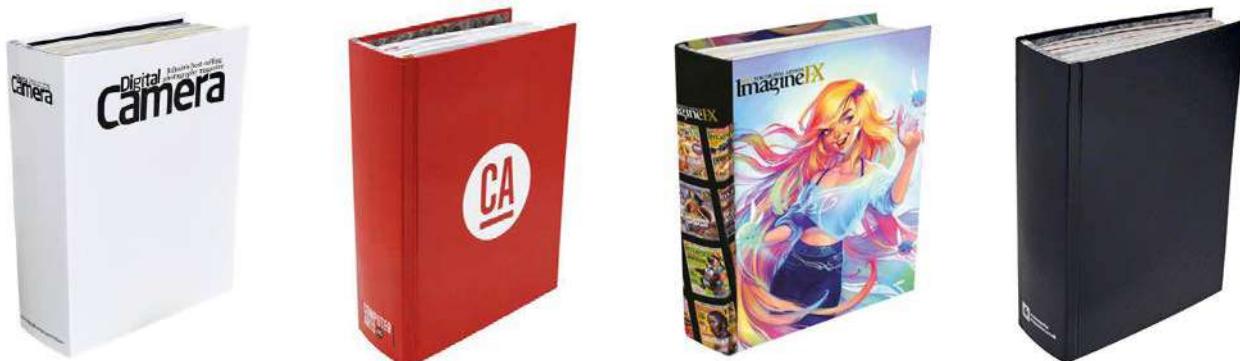
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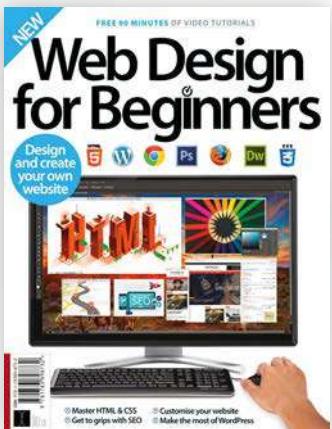


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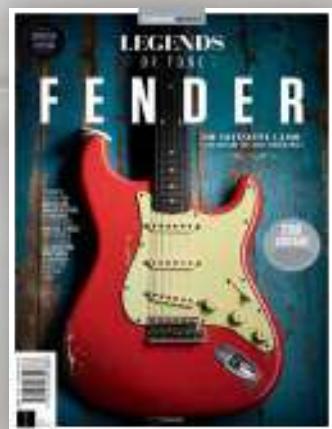
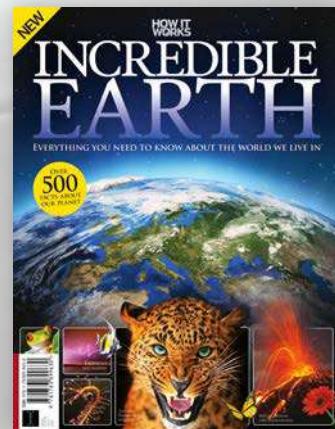
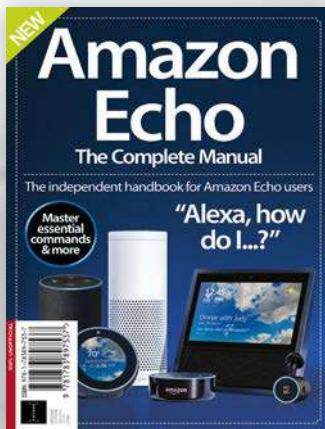


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